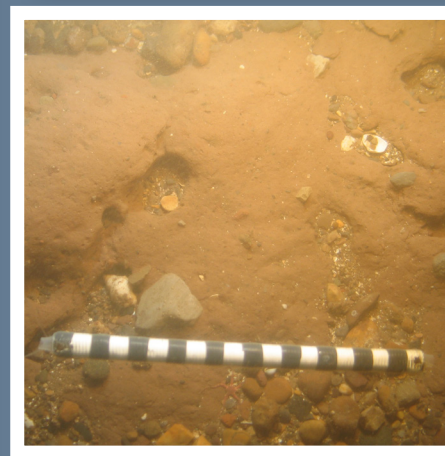
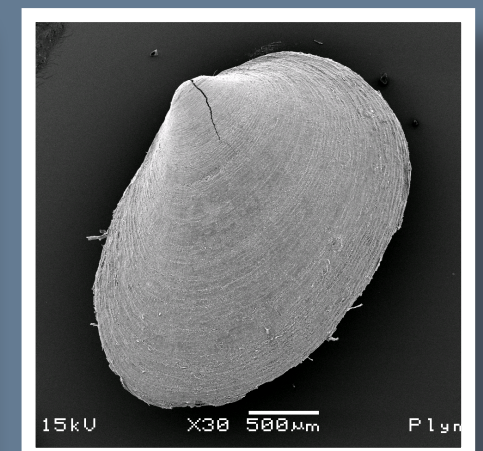
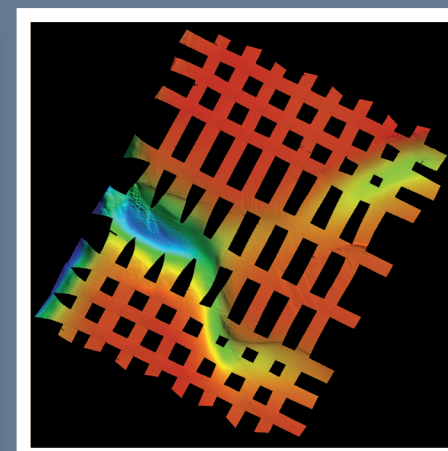
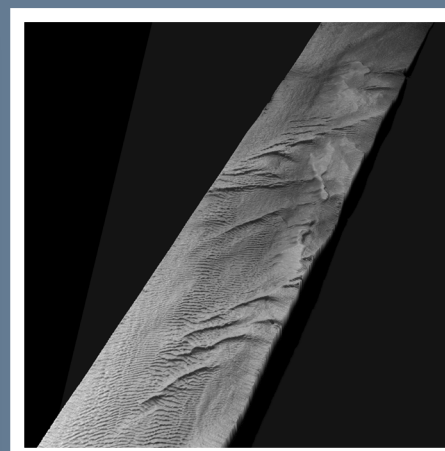
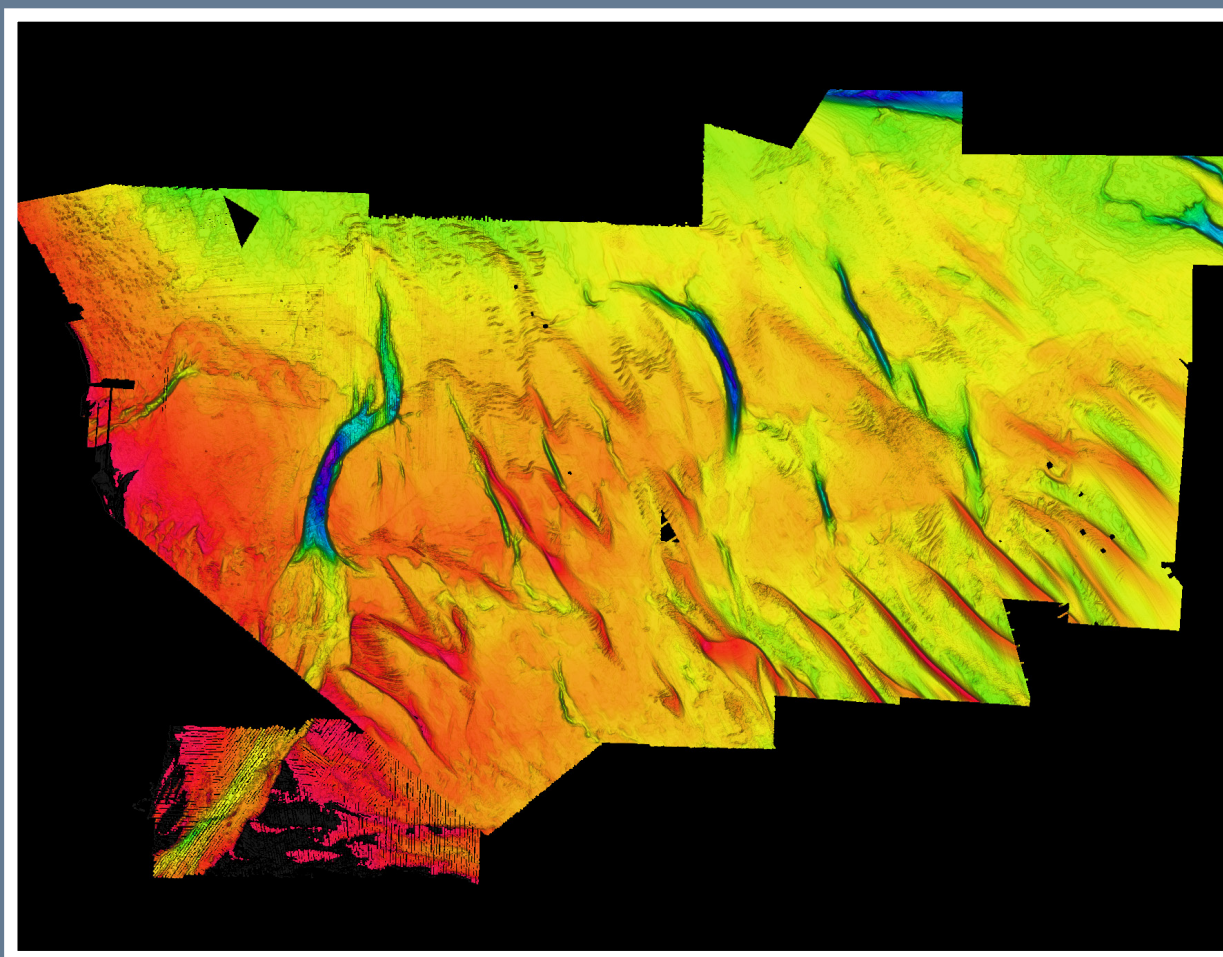
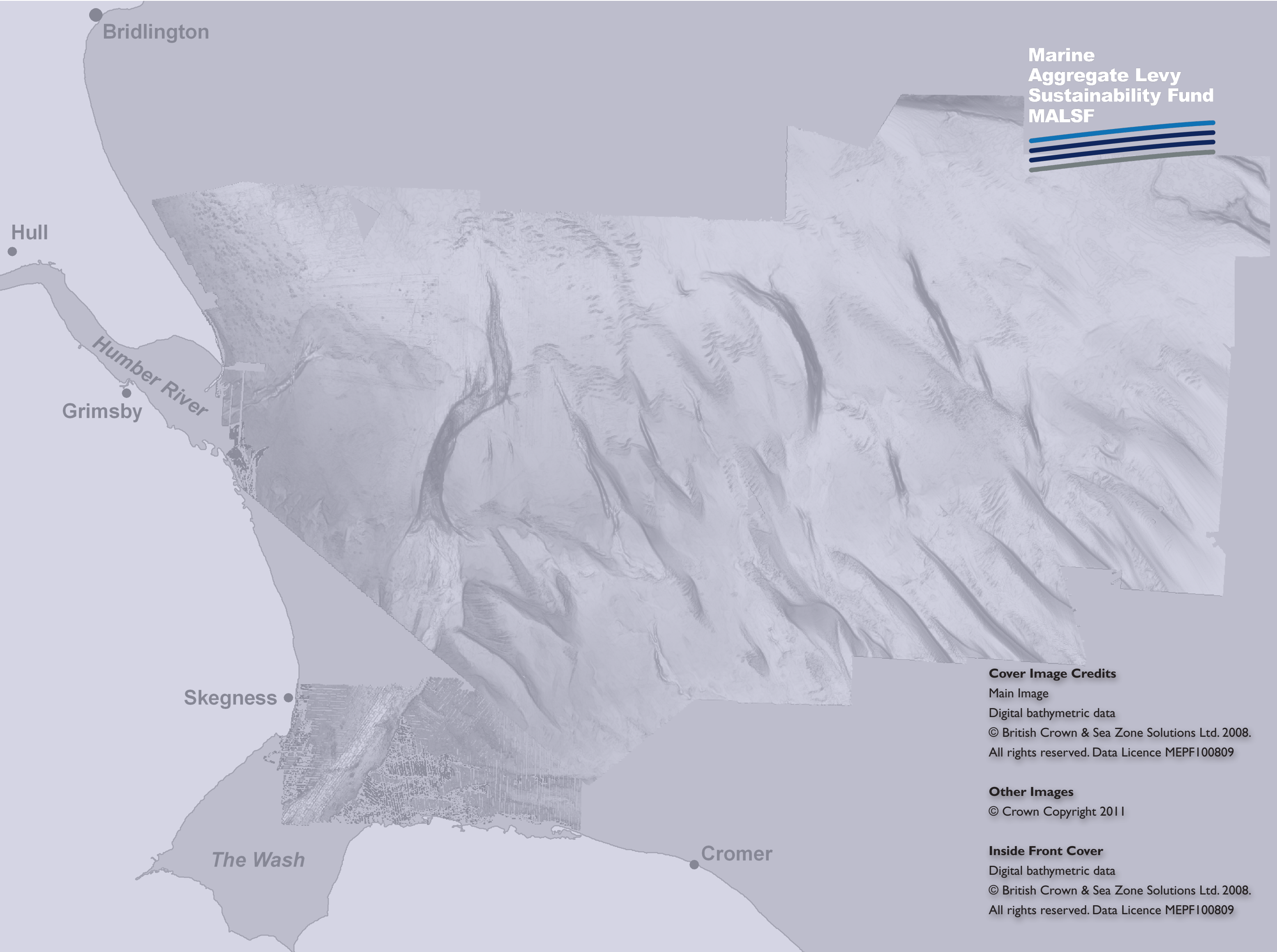


The Humber Regional Environmental Characterisation





**Marine
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MALSF**



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The Humber Regional Environmental Characterisation

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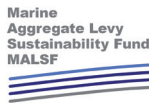
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Background to the fund

In 2002 the Government imposed a levy on all primary aggregates production (including marine aggregates) to reflect the environmental costs of winning these materials. A proportion of the revenue generated was used to provide a source of funding for research aimed at minimising the effects of aggregate production. This fund, delivered through Defra, is known as the Aggregate Levy Sustainability Fund (ALSF); **marine** is one element of the fund.

Governance

The Defra-chaired MALSF Steering Group develops the commissioning strategy and oversees the delivery arrangements of the Fund.

Delivery Partners

The Marine ALSF is currently administered by two Delivery partners — the **MEPF** (based at Cefas, Lowestoft) and **English Heritage**.

MEPF reports are available from www.alsf-mepf.org.uk.

MEPF source data is available from www.marinealsf.org.uk. For more information on Humber REC outputs please refer to Section 1.7

Where applicable, MEPF source data (e.g. survey data) is available from the Marine GIS secure data storage facility at www.marinealsf.org.uk. Project final reports are also available from here.

For more information on English Heritage please visit www.english-heritage.org.uk

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Executive summary

1. The Humber Regional Environmental Characterisation (REC) is a multidisciplinary marine study of the geology, biology and archaeology of an area of 11 000 km² off the east coast of England. It was funded by the Marine Aggregate Levy Sustainability Fund (MALSF).
2. Within the REC area, there are 12 active aggregate licences with applications submitted for 10 more. Within the region there is also gas production, wind energy development, and intensive shellfish harvesting. Without proper management of the sea bed areas there could be conflict over development of resources in the area.
3. The overall objective of the REC project was to provide integrated broadscale seabed maps in order to support the sustainable management of offshore resources now and into the future. The basis of the maps is a regional assessment of the physical, biological and archaeological environment. Here for the Humber REC area we present the results of each individual project element together with their integration into a holistic overview of the marine environment.
4. In addition to SeaZone single beam bathymetry, data from three geophysical and one sampling survey provided the basis for the interpretation. BGS legacy data supplemented the new data set. In total these data provided a sound basis for reporting on the regional character of the geology, biology and archaeology of the area.
5. The geology of the Humber REC area is characterised by a western gravelly region, a sandy eastern one and a transitional area in between. Outside of large sand banks and areas of sand waves the mobile sediment cover is thin. The terminations of the outer Norfolk Banks are located in the southeast of the area, and a series of low amplitude sinuous and linear banks are found in the southwest and centre. A number of arcuate and linear deeps, with a radial pattern incise the seabed.
6. The morphology and sediment distribution are attributed to a number of episodes; initially the region was glaciated and the Bolders Bank till Formation was laid down. After deglaciation the till was eroded to leave a thin coarse-grained relict deposit. As sea level rose the area was transgressed, the relict deposit

winnowed and fine grained sediment was transported into the area from the south. This sediment was reworked into the sand banks and sand waves present today over much of the sea bed. The dominance of gravelly sediment in the nearshore areas is the result of strong currents.

7. The Humber REC area is a region which is rich in archaeology, with finds ranging from the Palaeolithic to World War II. The archaeological material in the Humber REC region can be found both on and beneath the seabed. This archaeological material can be grouped into three main categories, prehistoric, maritime and aviation, all of which are present within the study area.
8. Several locations of archaeo-environmental potential were discovered during the Humber REC which directly relate to the regions prehistoric archaeological potential. Most of this potential is present in major channel systems within the south and east of the study area and dates to the Mesolithic period.
9. The submerged prehistoric resource has been characterised. This has been derived from the spatial mapping for the Mesolithic period. Evidence for earlier periods of prehistory is limited within the study area. The characterisation of the Mesolithic landscape indicates that where suitable preservation conditions exist there may be a large resource of material present.
10. The maritime archaeological resource from the late 19th century onwards can be located across the study area and has also been spatially mapped and characterised. No evidence was found for pre 19th century wrecks, despite documentary evidence indicating their presence.
11. The Humber REC area has also been a focus for aviation activity, particularly during World War II, and correspondingly, wrecked aircraft are likely. As most aircraft break up on impact, the wreckage is not commonly intact and can be hard to locate. As such, the number of aircraft wreck sites known to be present within the study area is assumed to represent only a small proportion of incidents, but are possibly more likely in areas on routes to and from World War II targets such as nearby airbases and Kingston upon Hull.
12. Analysis of the biological data collected across the Humber REC study area revealed four functional biological communities.

13. The most common community '*infaunal polychaetes with burrowing bivalves and amphipods*' was recorded across much of the mid and eastern sections of the study area in sandy deposits. The second most abundant community was characterised by '*barnacles, ascidians and tubiculous polychaetes*' and was associated with coarser, mixed sediments with suitable areas for attachment. In some areas where the REC study area was influenced by higher levels of sand this community was replaced by a '*Sabellaria spinulosa* reef' community. A small number of locations, in both mixed and sandy sediments, were found to support a very sparse biological community.
14. The biological communities were found to correlate strongly with the composition of sediment deposits, but were also influenced by shear bed stress and stratification of the water column. Predicted biotope distributions maps were created for the Humber REC study area utilising the EUNIS habitat classification scheme and habitat suitability modelling. Both methods yielded maps which are suitable for marine management purposes. However, since the EUNIS scheme forces a split on a limited set of environmental variables, which did not correlate strongly with the biological communities, it was felt that this method led to an overly complicated map with many communities occurring in multiple habitats. The EUNIS habitat model and RECHUM functional community model were combined to create a full coverage biotope model equivalent to EUNIS Level 5.
15. A number of rare and alien species were identified across the Humber REC study area including the tiny bivalve *Coracuta obliquata*. This is only the second record of this species from British waters in the last 100 years. The invasive American Slipper limpet was also observed and it is thought that these records may indicate a northwards shift in the range of this species, possibly associated with a warming climate.
16. Potentially important Annex I reef habitats were found in association with the Silver Pit. The reefs were predominantly created by the Ross worm *Sabellaria spinulosa* although high densities of the blue mussel *Mytilus edulis* were also identified. It seems likely that there is a cyclical succession occurring between these two reef building species driven by minor changes in environmental conditions and recruitment success.

1 Introduction

1.1 Background

The marine environment is under increasing pressure from (often conflicting) users and stakeholders who wish to utilise resources that are vulnerable to over-exploitation. The Coastal Access Act, 2009 proposes that marine planning be based on ‘an ecosystem based approach to marine management’ and a new system of marine planning is now being introduced around the United Kingdom with clear goals to enable Government to, i) set a clear direction for managing our seas, ii) clarify objectives and priorities, and iii) direct decision-makers, users and stakeholders to a more strategic and efficient approach towards the sustainable development and protection of marine resources. Rather than being mainly reactive to individual developments it is designed to take a more strategic approach, thereby allowing a more informed consideration of the best use of resources within the marine domain.

Fundamental to these aims is a requirement for an improved regional understanding of the marine environment, both living and non-living, especially in those areas where significant development may take place that, i) impacts on the marine environment and ii) may lead to conflict over the access to resources.

It was with these considerations in mind that the Marine Aggregate Levy Sustainability Fund (MALSF), in 2007, set up four scientific studies in areas where there is extensive aggregate extraction. The overall objective of the studies was to provide a baseline report on the natural environment of each area at the time the study was completed. These studies, termed Regional Environmental Characterisations (RECs) are located in the English Channel (South Coast REC), off the Thames Estuary (Outer Thames Estuary REC), off East Anglia (East Coast REC) and off of the Humber Estuary (Humber REC). The areas represent the remarkable variability of the natural marine environment of the UK shelf. They are also subject to increasing development and exploitation of marine resources.

This report focuses on the area off of the Humber Estuary, a region of particular importance because of the considerable exploitation of marine resources taking place there. There is a long history of fishing activity that includes bottom trawling in the deeper waters of the eastern part of the area, and an intensive shellfish industry in

the near shore areas in the west. There are also numerous licenced areas where aggregate extraction is actively taking place. In the 1960's the area became important for the supply of natural gas to the UK market, and production still continues today. Most recently, it now promises to be one of the largest areas in the UK for the production of offshore wind power. All of these activities have an impact on the natural seabed environment and without adequate planning multiple and conflicting pressures from the different users may result in unsustainable development and conflict between the various stakeholders. The intensity of activity is especially high in the west of the area where much of the future development in fisheries, dredging and wind farm construction will take place.

1.2 Objectives and Design—Regional Environmental Characterisation

The overall objective of the REC projects is to provide integrated broadscale seabed maps in order to support the sustainable management of offshore resources now and into the future. The basis of the maps is a regional assessment of the physical, biological and archaeological environment. And, here for the Humber REC area we present the results of each individual project element together with their integration into a holistic overview of the marine environment. As planned, the main products are integrated broad scale sea bed maps. The comprehensive review of the prevailing natural environment of the outer-Humber region provides an improved understanding of the active natural processes. For aggregate extraction, the report forms a context for the Regional Environmental Assessment, carried out by the aggregate industry in the area. Based on this understanding, the REC provides an environmental baseline for future sustainable development of the marine area and effective management of important marine resources.

The project design mainly follows that of the Eastern English Channel Habitat Map (James *et al.*, 2007) and the South Coast REC (James *et al.*, 2010), although there are differences in organisation. With the South Coast (and Thames) RECs, the marine data acquisition and interpretation were separate contracts, whereas the Humber, and East Coast, RECs were let under a single contract. There has thus been a more integrated scientific approach throughout this characterisation project. An initial appraisal of all previously available data was presented in the Desk Based Report that formed the basis

of a programme of geophysical data acquisition. Interpretation of the geophysical data formed the basis of the following sampling programme. Processing of the acquired sample data was followed by its interpretation. Integration of all of the acquired data forms the basis of this final report.

The main objectives therefore were to carry out:

- 1 **Desk-based research:** To critically review all pertinent scientific data for the Region and identify gaps in knowledge and to use this to refine the survey work scope to ensure that acquired data is sufficient to be suitable for the likely avenues of interpretation.
- 2 **Geophysical survey data acquisition:**
 - a) to acquire additional new geophysical data in the Region and to target knowledge gaps.
 - b) to produce a detailed acquisition report.
- 3 **Sampling survey data acquisition:**
 - a) to acquire additional geological, archaeological and biological data in the Region and to target knowledge gaps.
 - b) To produce a detailed acquisition report.
- 4 **Mapping R&D:** To integrate new and existing geophysical, geological, archaeological and biological data to provide comprehensive maps of
 - a) the distribution of marine species and habitats (including those of conservation significance and fisheries importance),
 - b) seabed sediments,
 - c) integrated habitat maps, and
 - d) archaeological features and deposits/area of increased archaeological potential in the Region.
- 5 **Additional R&D:** To test causal relationships/correlations between the physical environment and associated fauna.
- 6 **Human Impacts:** To identify and record the nature and location of any obvious human impacts in the Region (e.g. dredge tracks, disposed or discarded material and trawl marks).

The project took place over two and a half years, between September 2008 and March 2011.

1.3 Location of the Study Area

The Humber REC Project area is located in the southern part of the North Sea, offshore the Humber Estuary, (Figure 1.1). It extends

160 km eastward from the coast almost to the UK Median Line. It covers an area of approximately 11 000 km². It lies 50 km to the north of the East Coast REC.

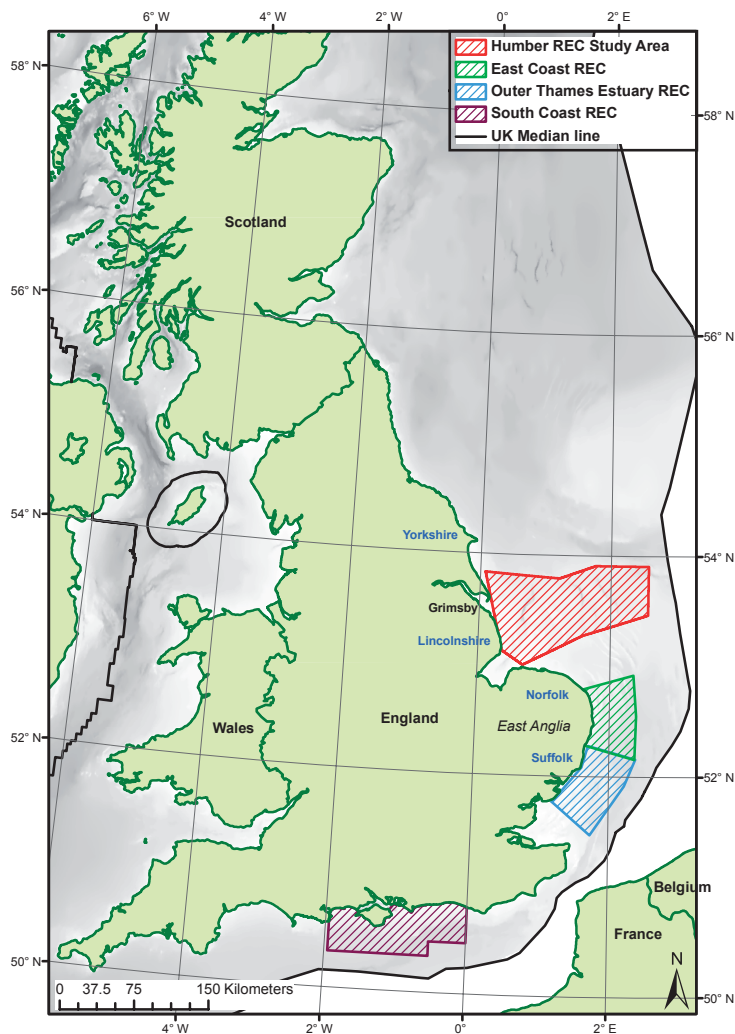


Figure 1.1: Location of the Humber REC.

1.4 Database

The broad scale maps produced are mainly based on the newly acquired geophysical, geological, biological and archaeological data, but much of the significant volume of BGS legacy data in the area was also accessed and utilised. Previous geological mapping by BGS took place over 30 years ago, before the availability of new digital data sets such as the UKHO SeaZone bathymetry data that

allow 3-D visualisation of the sea bed. SeaZone is xyz bathymetry data digitised from multiple UKHO survey sources including, but not limited to, individual depth soundings from paper plotting charts and single-beam bathymetry. Fledermaus is used to visualize the gridded data, allowing for a pseudo-3D view of the seabed. Integrating the bathymetric data with sub-bottom seismic allows for the creation of the three dimensional architecture of the seabed and the underlying sediments and rocks.

New archaeological data have been obtained from vibrocores of sediment in the region. Also, a new sampling, seabed imaging and seabed trawling programme has resulted in the acquisition of a regional biological data set that complements previous Environmental Impact Assessments associated with aggregate dredging and wind farm construction.

1.5 Report Structure

To present background information, details of scientific rationale, methodologies and results, the report comprises chapters on:

- 1. Introduction
- 2. Regional Perspectives
- 3. Project Planning, Survey Data and GIS
- 4. Geological Characterisation
- 5. Marine Archaeology
- 6. Biological Characterisation
- 7. Integrated Assessment of Habitats and Biotopes
- 8. Features of Interest
- 9. Gap Analysis, and
- 10. Conclusions

1.6 Study Team

The research has been undertaken by a consortium of organisations led by the British Geological Survey, and including, Birmingham Archaeology, Marine Ecological Surveys Ltd, and Gardline Environmental (Table 1.1). The BGS was responsible for overall project management, delivery of the geological aspects and preparation of the final report. Birmingham Archaeology was responsible for all prehistoric and maritime archaeology. MES was responsible for the reporting of the biology and the integrated biotope assessments. Gardline Environmental managed and delivered the geophysical and sampling surveys.





Organisation	Team	Role & responsibilities
	Dave Tappin	<i>Project Manager – Overall Reporting</i>
	Dave Tappin Dayton Dove	<i>Geological interpretation, Quaternary history, seabed sediment mapping, sedimentary processes</i>
	Diego Diaz Doce Rhys Cooper Jennifer Plim	<i>GIS sediment modeling, and, database</i>
	Amanda Hill	<i>Publications</i>
	Bryony Pearce Jackie Hill	<i>Biological reporting, analysis and interpretation, biotope assessments and food web analysis</i>
	Caroline Chambers Jennifer Pinnion	<i>Habitat suitability modelling & GIS</i>
	Mathew Green Jennifer Gallyot Lucy Georgiou Daniel Brutto Sara Marzialetti	<i>Commercial fisheries, ornithology, marine mammals, rare and alien species, conservation and benthic review</i>
	Sara Marzialetti	<i>Biological line drawings</i>
	Simon Fitch	<i>Geophysical Interpretation and palaeolandscapes</i>
	Ben Gearey Emma Hopley David Smith Philip Toms Peter Marshall Allan Hall Ian Boomer Pamela Grinter	<i>Archaeo-environmental assessment</i>
	Ellie Ramsey Henry Chapman	<i>GIS and Heritage assessment</i>
	Richard Bates (University of St Andrews)	<i>Geophysical Interpretation</i>
	Vince Grove	<i>Marine survey coordination</i>
	Doug Stewart	<i>Analysis of underwater imagery</i>

Table 1.1: The Humber Coast Regional Environmental Characterisation study team.

1.7 Outputs

The result of the project is a major new environmental assessment of the Humber REC region. The report provides new maps of:

- a. Seabed morphology,
- b. The distribution of marine species and habitats (including those of conservation significance and fisheries importance),
- c. Seabed sediment distribution,
- d. Palaeolandscapes, that allows new insights into human occupation of the area in the Mesolithic, and,
- e. a map of Human Impacts on the seabed.

and descriptions and interpretations of the environments present in the Humber REC area.

Attached to the back cover of the report is a DVD-ROM that includes appendices of data, analysed or interpreted results, plus a pdf copy of the report and the reports from the marine surveys (Gardline, 2009; Tappin, 2010) available from <http://www.alsf-mepf.org.uk/>.

An ArcMap GIS and associated database has been included in the DVD. ArcExplorer software (www.esri.com/software/arcexplorer/) which enables free display, query, and retrieval of Humber REC GIS data has also been loaded on the DVD. Some aspects and results of the study are also available on the BGS website (www.bgs.ac.uk).

The ALSF Marine GIS database (<http://www.marinealsf.org.uk/>) provides access to marine aggregate research project metadata information and digital reports. The database holds a copy of this report, the survey data from the Humber REC 2008/2009 and the interpreted data. The database can be accessed using text and GIS map-based searches.

2 Regional Perspectives

The Humber region forms part of the well studied area of the UK shelf, the Southern North Sea Basin, with an extensive published literature of peer-reviewed scientific papers, reports, maps and charts.

Bathymetry of the area has been acquired over 100's of years, originally from individual lead-line soundings, subsequently by single beam echo soundings, and most recently with multibeam echosounding bathymetry (MBES) that provides almost complete seabed coverage of the areas surveyed. Much of this data is now available digitally. Oceanographic data have also been acquired from the area over a long period, and digital datasets that have been synthesised and modelled are available from the Atlas of UK Marine Renewable Energy Resources: Technical Report, <http://www.renewables-atlas.info/index.asp>.

Geological research in the Southern North Sea region dates back to the early 20th century, when the first seabed samples were acquired from the nets of trawlers (e.g. Whitehead and Goodchild, 1909), and the first, rudimentary, maps of sea bed sediment distribution were produced (e.g. Tesch, 1910). The development of the echo-sounder led to the first study of bed forms in the area (van Veen, 1935). Research on the pre-Holocene geology of the southern North Sea was initiated in the late 1960's when the Mesozoic formations exposed on the cliffs of north east England were traced offshore, where they lie at sea bed or beneath the thin Quaternary cover. (Donovan, 1963; Dingle, 1965; Donovan, 1968; Dingle, 1971) The discovery of gas deposits at Slochteren, Holland in 1959, led to exploration in the southern North Sea that resulted in 1966 in the first commercial gas find at the West Sole Field, and the first gas piped onshore in 1967. The large volumes of geophysical, rock and petrophysical data resulting from the exploration activity led to a massive expansion in marine geological research in the region and major advances in understanding its geological evolution. In the late 1960's, the BGS began a 25 year programme of mapping the geology of the UK shelf that resulted in the publication of 1:250 000 scale of maps of the Solid (bedrock) and Quaternary geology and Sea Bed Sediments of the offshore area. The first time any country in the world had carried out such a programme of research and mapping.

Prehistoric archaeological research in the region originated with Clement Reid, and the first published map of the prehistoric landscape (Reid, 1913). The discovery of the Leman and Ower point in 1932 (Clark, 1932) prompted the first archaeological palynology (Clark, 1936). After a long hiatus, it was not until 1998 however, that new interest was stimulated by the publication of speculative offshore maps of the palaeolandscape and the naming of the area 'Doggerland' (Coles, 1998). This stimulated further interest into the archaeology of the area, and resulted in the North Sea Palaeolandscapes Project (NSPP) that, using 3D seismic data, led to the extensive, detailed mapping of the Mesolithic landscape of the southern North Sea basin (Gaffney *et al.*, 2007).

Research on the maritime history of the Humber REC region and its wrecks is minimal. Maritime archaeology, however, is becoming of increasing importance as exemplified by several recent publications (English Heritage, 2002a, b; Wessex Archaeology, 2006a, b). Broader scale, heritage research in the project area includes the Navigational Hazards Project (Merritt *et al.*, 2007) and private research on military aircraft conducted by individuals such as Ross McNeill (unpublished).

Extensive research has been carried out into the distribution and function of biological assemblages across the Southern North Sea area (Petersen C G J. 1914; 1918; Sparck 1935, Remane 1940; Jones 1950; Glemarec 1973), including some very broad scale mapping projects initiated by the International Council for the Exploration of the Seas (ICES) between 1986 and 2002 (Kunitzer *et al.* 1992; ICES 2007; Reiss *et al.* 2010). A wealth of biological data has also been obtained through the Environmental Impact Assessment (EIA) process associated with offshore developments (MESL, 2003, Pearce 2008), providing comprehensive biological data on a much more localised scale. This REC programme has been designed to map the area at an intermediate, regional scale, providing data that is sufficient to characterise biological assemblages and identify areas of conservation interest.

2.1 Physical Setting

The Southern North Sea forms a semi-enclosed basin, bounded to the west by the UK and to the east by mainland Europe (Figure 2.1.1). Open to the north, to the south there is a narrow outlet through the Dover Straits. Immediately to the north lie the

shallow waters of the Dogger Bank, separated from the Humber REC area by the deep waters of the east-west trending Outer Silver Pit. To the south lie the Norfolk Banks, northwest to southeast trending sand banks. To the southwest lies the major embayment of the Wash, and immediately to the west is the Humber Estuary.

Within the Humber REC area water depths (Figure 2.1.1) are mainly shallow and, apart from the major deeps and sand banks, increase eastward from the coast across a gentle regional gradient to 30 m in the east (Figure 2.1.2). The seabed is gently undulating but, superimposed upon the regional gradient, there is a prominent localized, relief formed by a number of large-scale features that include deeps and sediment banks. Most prominent are the major deeps of Sand Hole, Silver Pit, Sole Pit, Coal Pit, Well Hole and its' southern extensions, and Markham's Hole. These deeps form elongate, linear and curvilinear submarine valleys, with the base of the Silver Pit up to 80 m below the surrounding seabed. The deeps are not channels as such because they are scoop (scaphiform) shaped, increasing in depth in both longitudinal as well as transverse directions. They are also referred to as tunnel-valleys (e.g. Ehlers *et al.*, 1984) and they form a radial pattern with their axis in the north.

The sediment banks are oriented in a, generally, northwest to southeast direction. In the southeast they form the northwest terminations of the Norfolk Banks with a relief of up to 20 m. In cross-section, the banks are asymmetrical with the steeper, scarp slopes mainly facing northeast. Banks also lie between the Silver and Sole pits, again showing a dominant northwest to southeast orientation. However, in cross-section these are mainly symmetrical or asymmetrical to the southwest. In the southwest of the area there are a series of sinuous, 'zigzag' shaped banks e.g. Race Bank, again orientated roughly northwest to southeast (Figure 2.1.2).

Smaller-scale seabed features include sand waves of various sizes. These are mainly located to the east of the Silver Pit, with orientations orthogonal to the banks, generally between northeast to southwest and east-west. The sea bed to the west of the Silver Pit is mainly planar and undulating with areas of low amplitude sediment waves up to one metre in height. Offshore, and south of Flamborough Head irregular, but generally linear, seabed prominences up to 5 m high lie parallel to the coast.

The present day seabed physiography is the result of a number of processes, mainly acting over the past ~15 000 years. The basic

sea floor fabric approximates to the morphology of the pre-Holocene land surface, formed when sea levels were lower during the last, Devensian, glaciation. The southern margin of the Devensian ice sheet lay across the REC area. As the ice retreated, the till of the Bolders Bank Formation was laid down and outwash sediment was deposited by rivers issuing from the ice front. With ice melt, post-glacial sea levels rose, resulting in a substantial modification of the area through both sediment accretion and erosion. The glacial outwash sands were reworked into banks, notably the Norfolk Banks in the southeast and the sinuous banks in the southwest. Any glacial sediment infilling the deeps would have been eroded by the strong tidal currents (see below). Finally, when the sea reached its present level, the regime we see today stabilised into a dynamic equilibrium between the hydrodynamic regime and sediment availability

2.2 Oceanography

2.2.1 Tides

Tidal currents in the Humber REC area are locally strong. Mean spring tidal current velocities vary from less than 0.5 m/s to 1.7 m/s increasing to 2.0 m/s in localized, near shore areas (Figure 2.2.1) (DTI, 2008). Tidal flux becomes more intense and complex towards the Wash (Kenyon and Cooper, 2005). Nearer to the coast mean spring near-surface tidal current strength ranges between 0.75 m/s to 1.25 m/s (Sager and Sammler, 1975) and depth averaged extreme surge currents are between 0.6 and 0.8 m/s (Flather, 1987). Near-bottom velocities are lower than those at the surface by only a small amount because of the shallow water depths. Evidence from south of the project area, shows that near bottom currents may be up to 1 m/s in zones of active sand waves (Smith, 1998).

Amplification of the tidal wave in the Southern Northern Sea results in a large tidal range along the east coast of England (Figure 2.2.2). Mean spring tidal range is between 2 and 6 m. On the open coast, maximum tidal ranges are between the Humber and the Wash; at Skegness (Figure 2.1.2) the mean Spring range is 6.1 m and the mean neap range is 3.0 m. Minimum ranges occur farther south off of East Anglia. Hydrodynamic modelling for the Silver Pit suggests that, within the deeps, current velocities are increased. (Pingree and Griffiths, 1979). The dominant longshore drift is southerly, as opposed to tidal surges that are predominantly to the north.

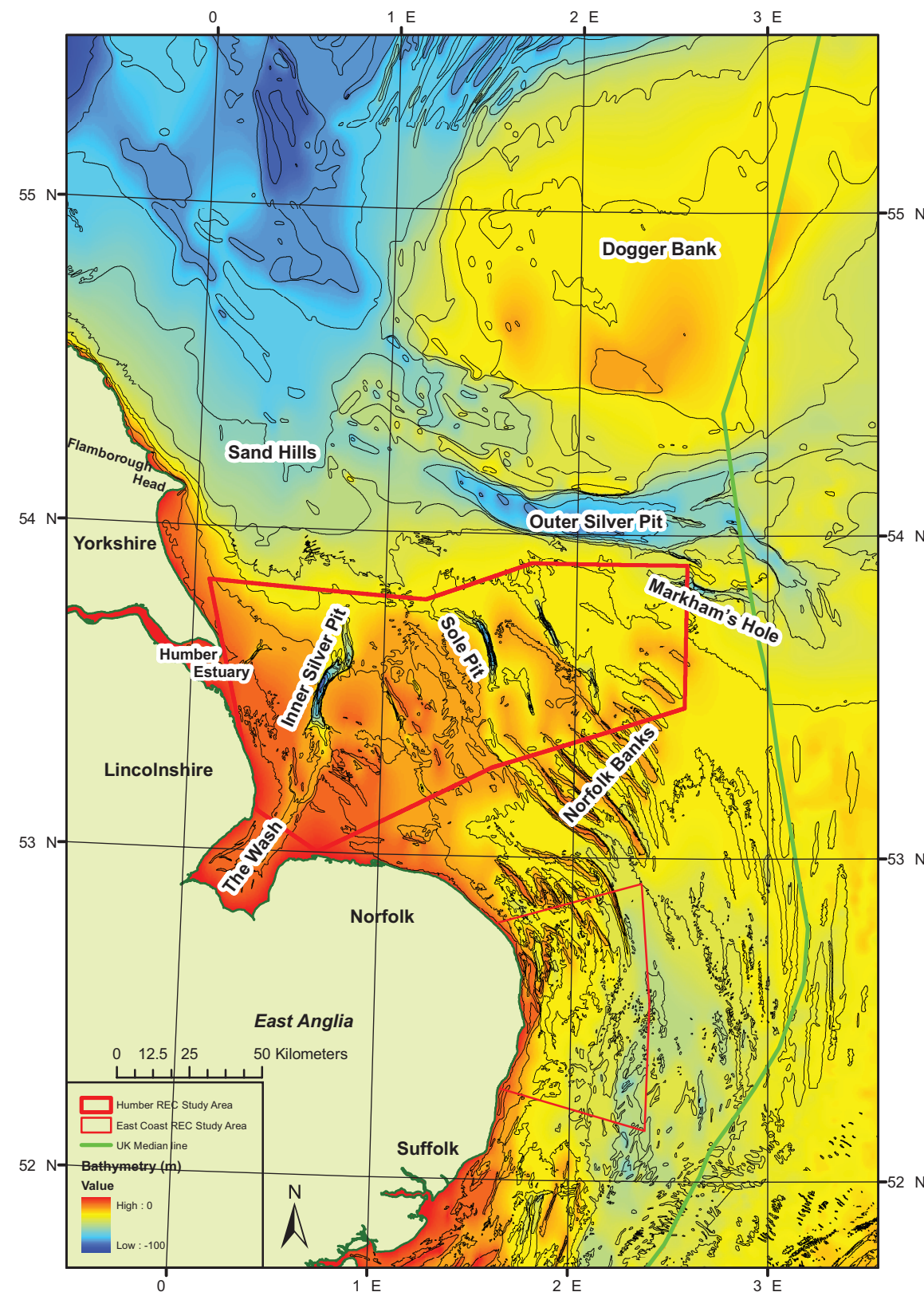


Figure 2.1.1: Bathymetry of the Humber REC region.

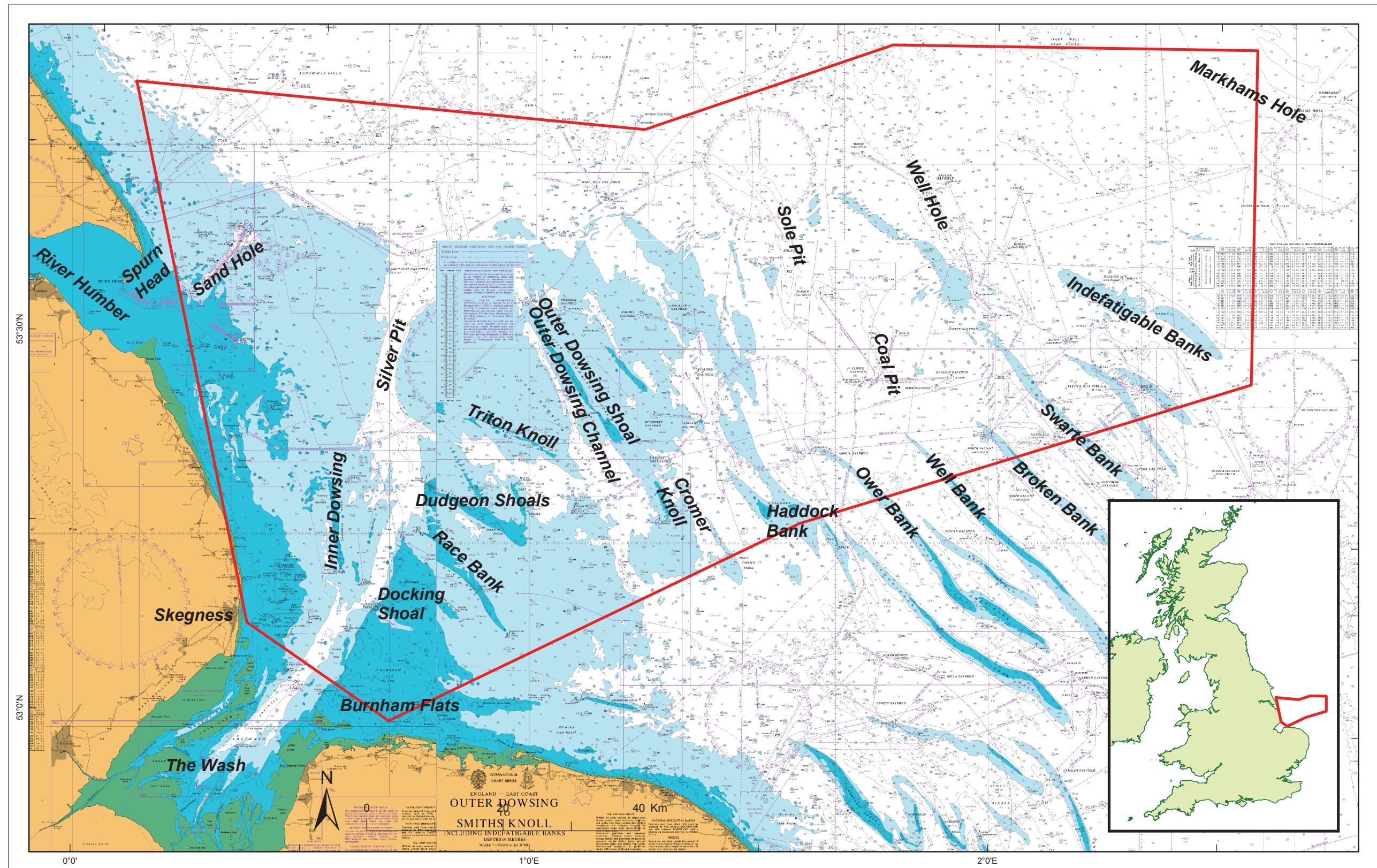
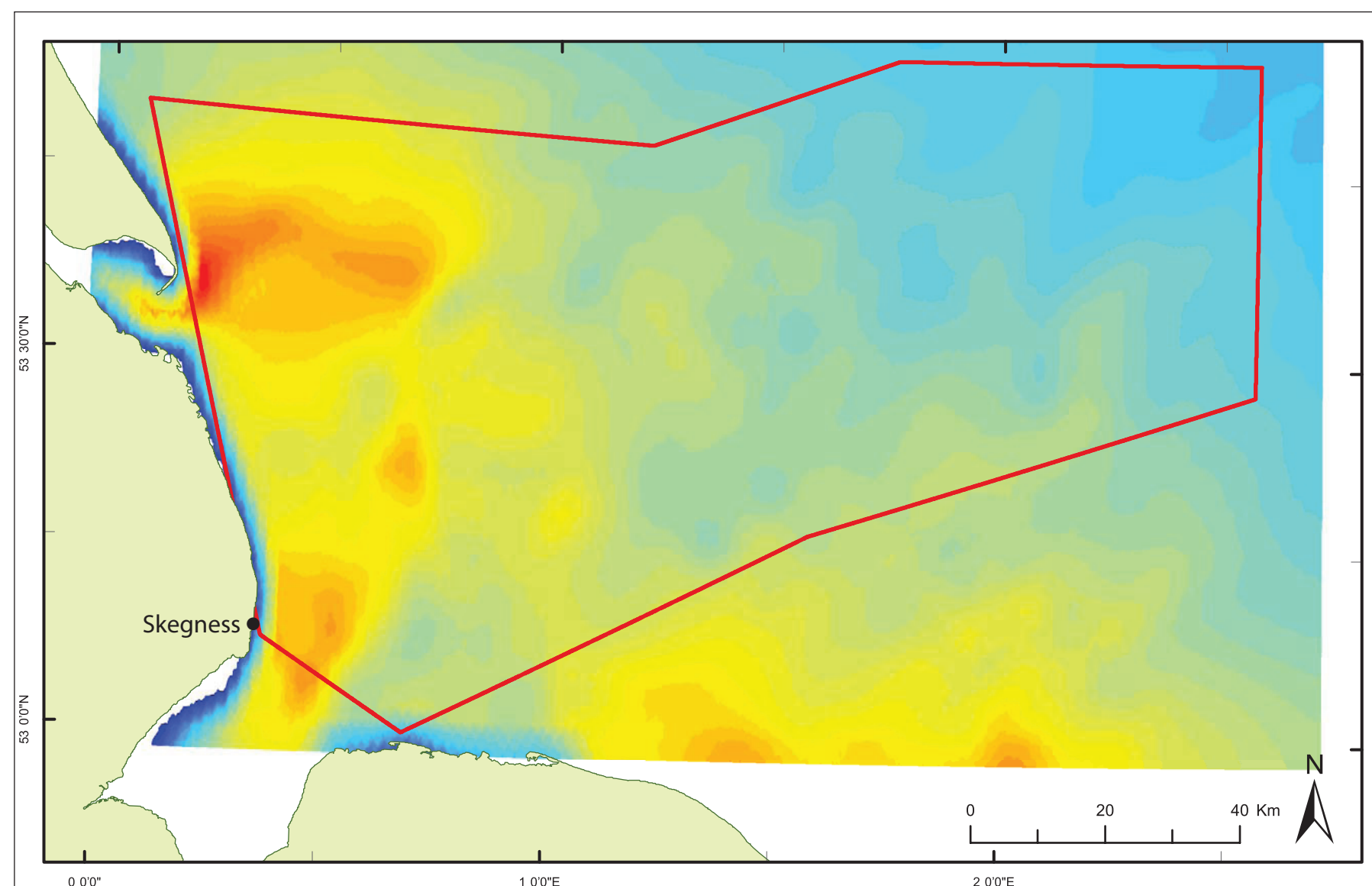
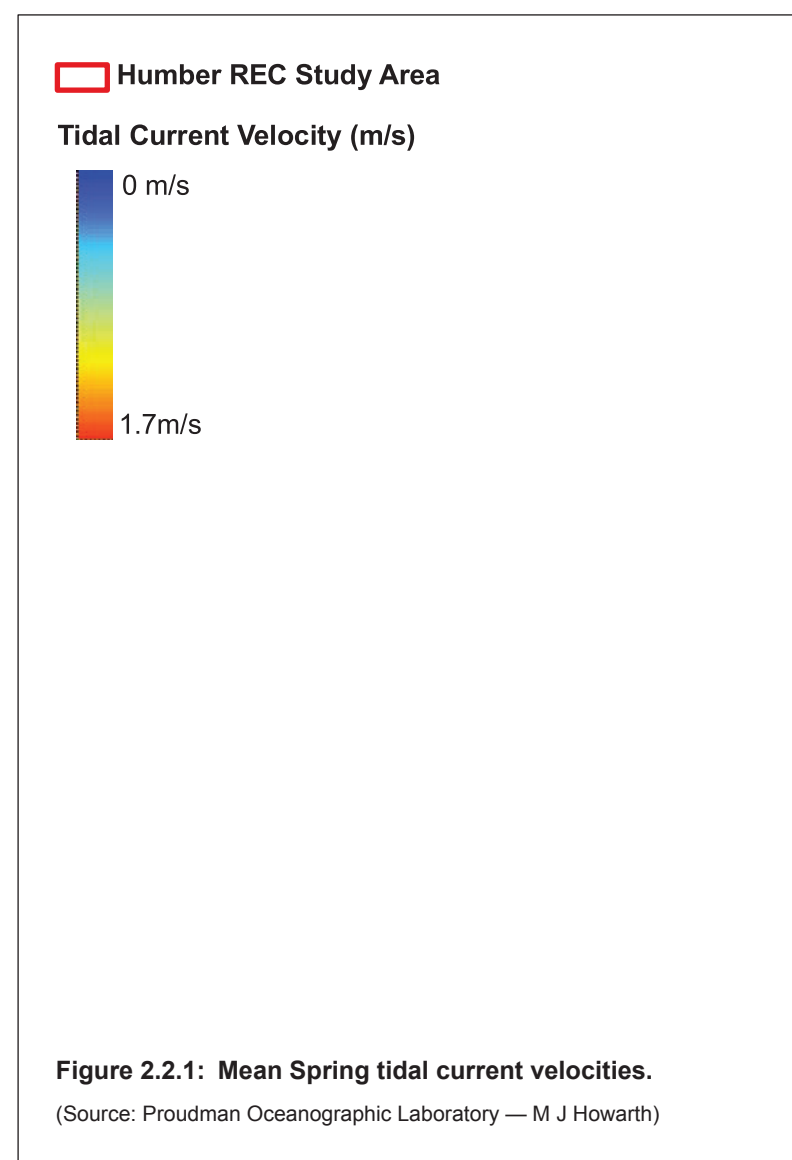


Figure 2.1.2: Bathymetry of the Humber REC and significant seabed feature names.

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2.2.2 Wave Energy Climate

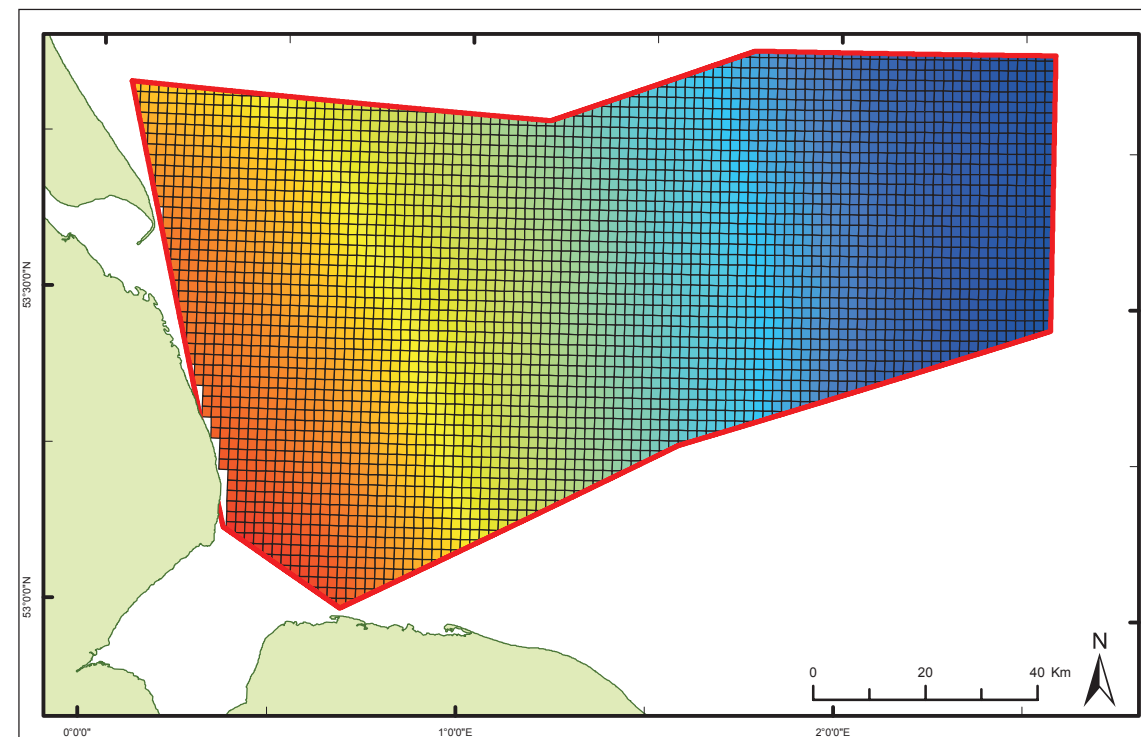
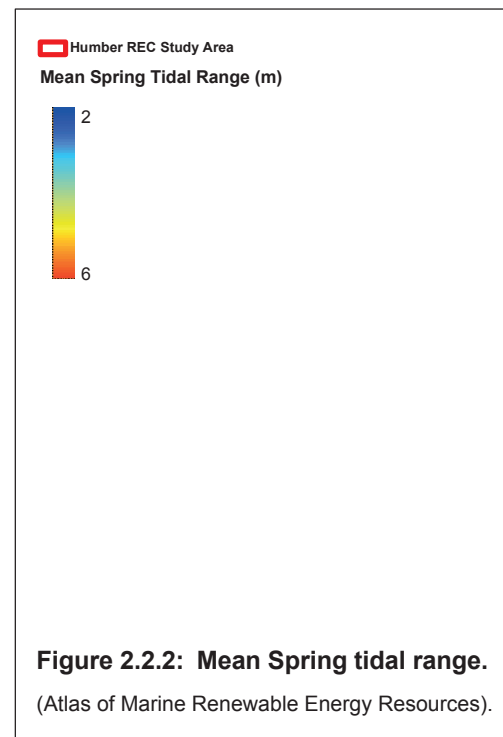
Wave-energy is dependent upon the friction action of the wind on the sea surface that drives directional sea-surface and storm surge currents. These in turn drive non-directional rotational near-bed currents when wind and swell waves interact with the seabed. In the Humber REC area the wind is predominantly from the SSW, with annual mean speed range between 6.5 to 9.5 m/s. Annual wave height ranges between 0.5 and 2 m (Figure 2.2.3). Annual mean wave power ranges from approximately 0 to 10 kW/m of wave crest.

The influence of waves and wind-driven currents on the seabed is unpredictable because it is dependent upon a combination of

changes in the wind patterns and the shelter provided by land and the offshore banks and ridges. This is in contrast to tidal current stresses which vary more predictably, as they are dependent on the cyclical flood and ebb of tidal streams. One effect of wave interaction with the seabed in shallow water, particularly during storm events, is a tendency to flatten sand waves and other mobile seabed bed forms that may have been previously constructed by the tidal currents. Thus sediment is redistributed laterally leading to the widening of banks and ridges on the open shelf and in the flats of the estuaries.

2.3 Geology

The geology (including bedrock, Quaternary and sediment) of the Humber REC has been well researched (see synopsis by Cameron *et al.*, 1992). Of most relevance to the present study, are rock and sediment at or within metres of the sea bed. A map of the solid rock geology of the Humber REC area is included as Figure 2.3.1, however, unlike other RECs, such as the South Coast and the Thames, there are only very localised and small areas of bedrock exposed at seabed or within decimetres of the surface. Thus the relevance of bedrock to the Humber study is limited. As a consequence, only a brief description of the relevant rock units is included here.



Of more importance is Quaternary sediment and the sediment active under the present hydrodynamic regime. Quaternary glacial and interglacial deposits are the source of the present seabed sediment, so these are described in detail, as are the sedimentation processes presently active.

At seabed in the Humber REC area there is mainly a thin, mobile sediment cover with thicker Holocene sediments forming sand banks and sand waves. Many of these features are formed of gravel and are thus mainly inactive under the present hydrodynamic regime. Beneath the sediment, and covering over 90% of the region, is the till of the Bolders Bank Formation, a source of much of the coarse sediment now present.

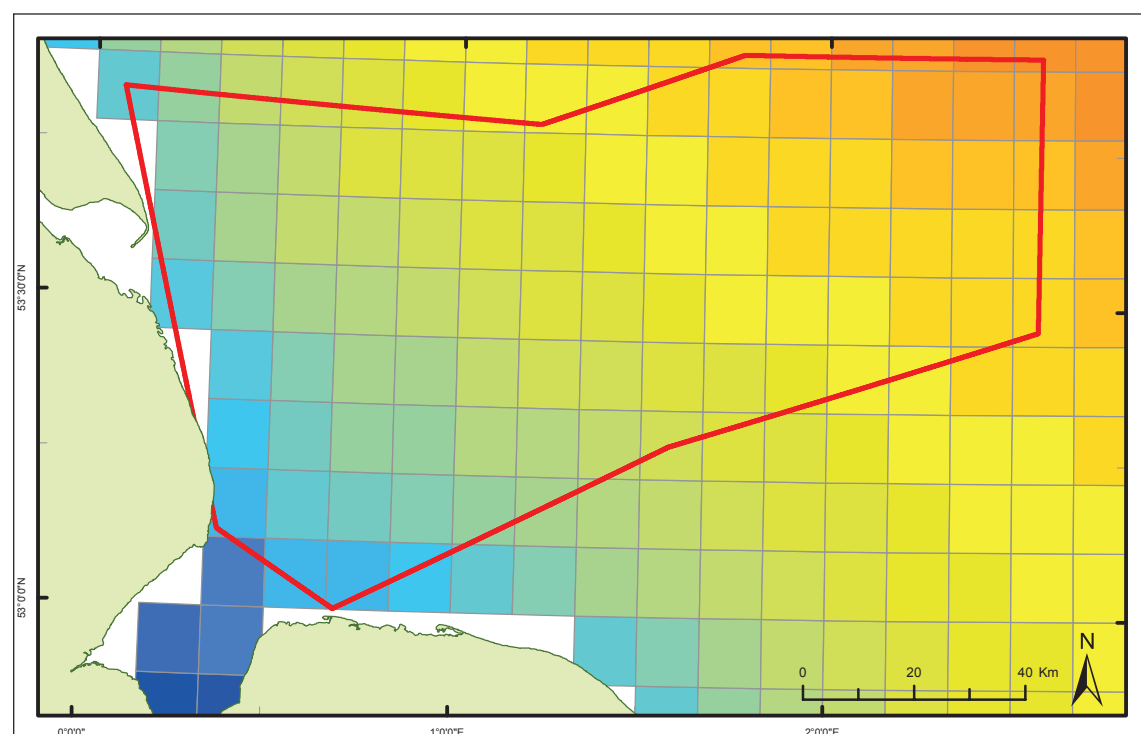
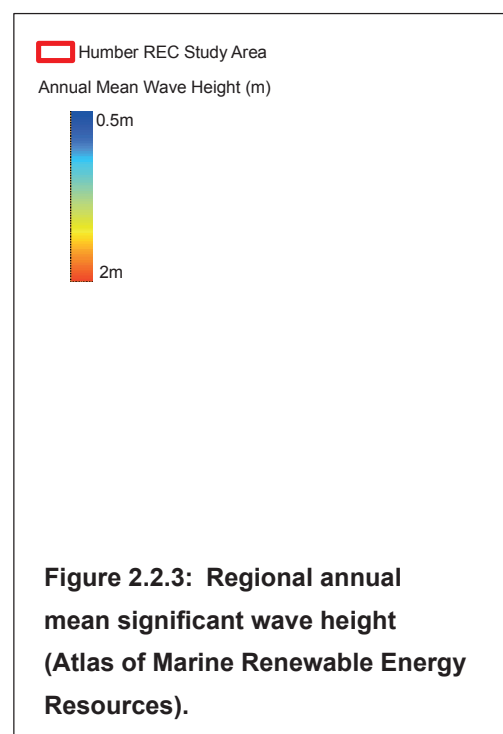
2.3.1 Bedrock Geology

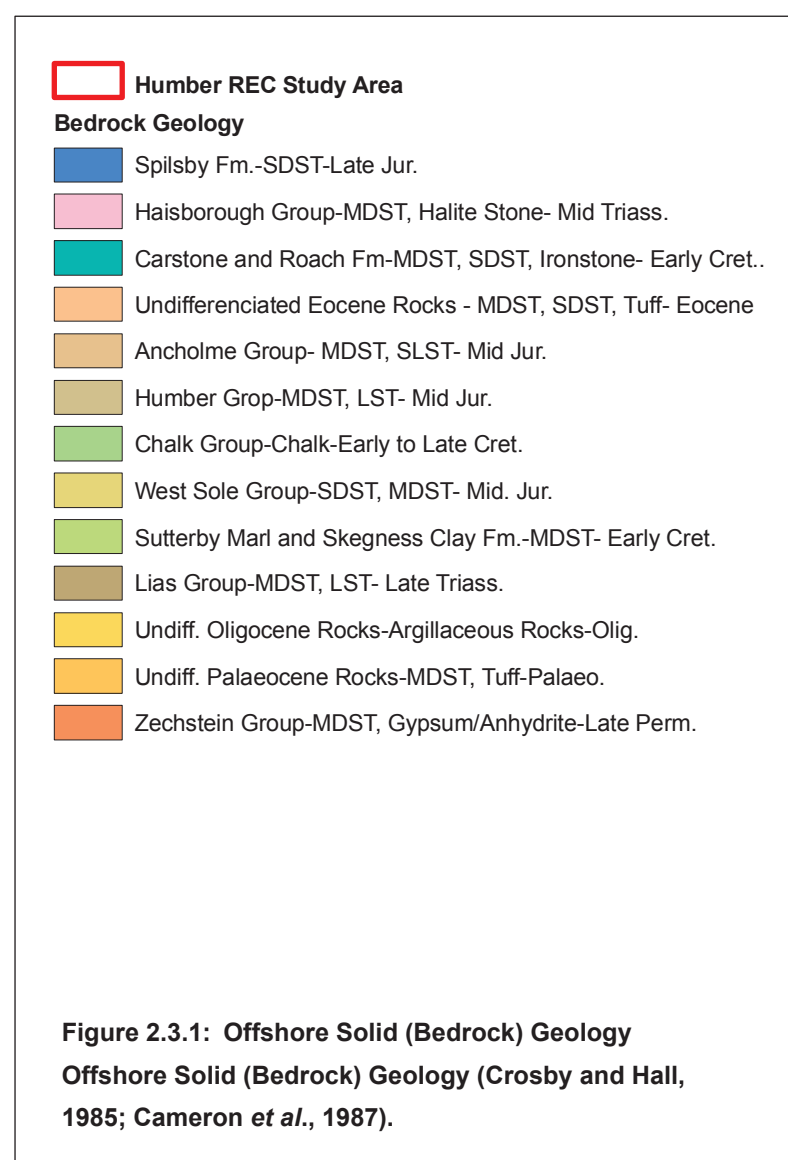
The only seabed exposures of pre-Quaternary rock (Figure 2.3.1) are in the Sole and Silver pits (Figure 2.3.2). Cretaceous chalk and marl is at seabed at the base of the Silver Pit and has been sampled in shallow cores. Further east, within the Sole Pit, lower to upper Jurassic rocks of the Lias, West Sole, and Humber groups are exposed. The Lias Group comprises shale and siltstone within beds of limestone and sandstone. The West Sole group is composed of sandstone with beds of shale and limestone. The Humber group contains the Kimmeridge Clay, a primary source rock for North Sea oil.

2.3.2 Quaternary Geology

It has been recognised for many years that much of the floor of North Sea was shaped during the last glaciation (Eisma and Kalf, 1979). At first, it was assumed that Pleistocene sediments were very thin because in East Anglia, they are less than 80 m thick. However, in the late 1970's a great thickness of Pleistocene sediment was found to be present throughout the North Sea Basin (Caston, 1977, 1979), that had accumulated through tectonic subsidence of the region. In the southern North Sea the greatest thickness (~600 m) of these deposits are of early to middle Pleistocene in age; laid down in shallow water, distal, deltaic environments (Balson and Cameron, 1985), that are extensions of major fluvial systems extending into the area from the Netherlands (Zagwin and Doppert, 1978; Zagwin, 1979, 1989).

The deltaic sediments are overlain by a thin cap of middle to late Pleistocene sediment (Cameron *et al.*, 1989) representing





alternating cycles of glacial and interglacial climate. During very cold periods, there was continental-scale glaciation and, as sea level fell, the Southern North Sea area was exposed to subaerial conditions. During warmer periods, as global climate ameliorated, sea level rose and the sea flooded the area.

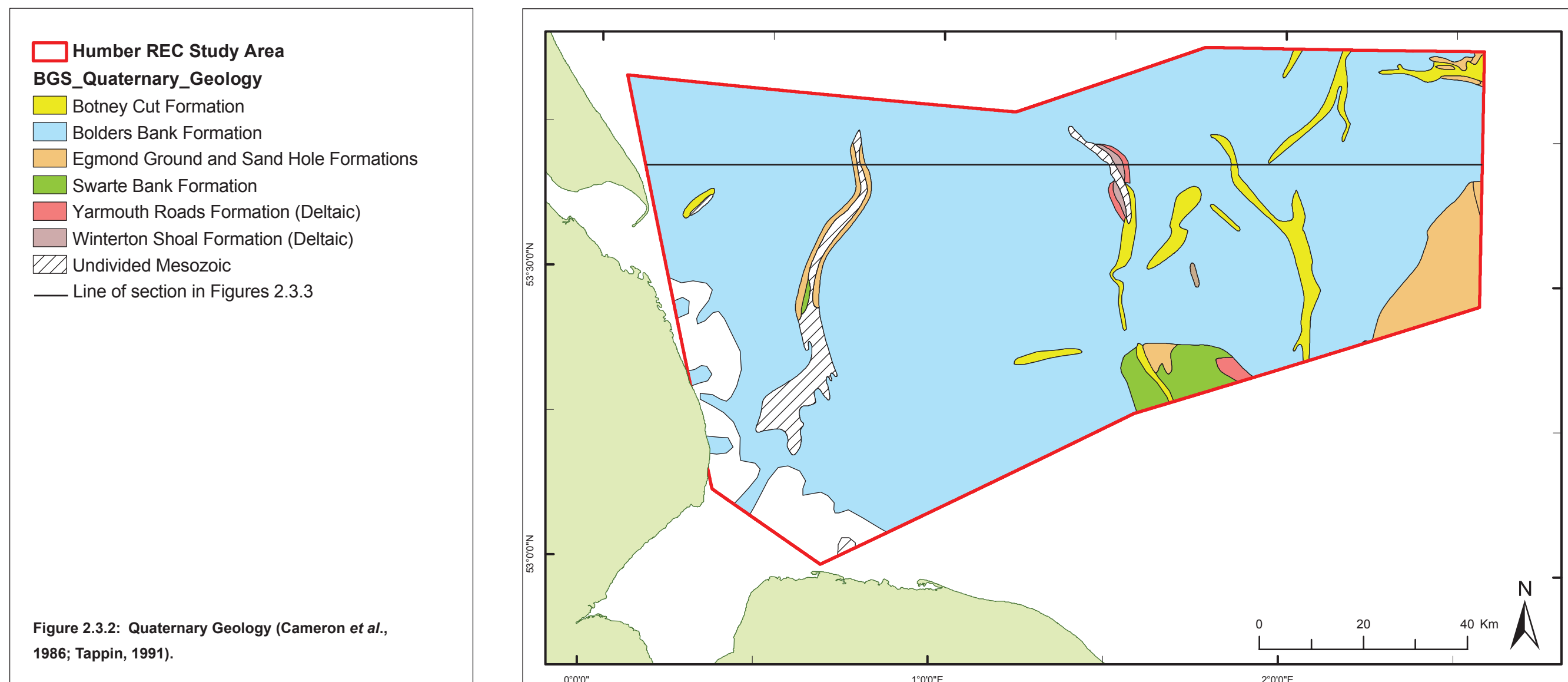
Within the area of the Humber REC, representatives of both the early Quaternary deltaic sediments and the later Quaternary glacial/interglacial sediments are present (Figures 2.3.2 and 2.3.3). The deltaic sediments are only exposed at seabed across a very small part of the area mainly along the flanks of the deeps and in the southeast. Of the glacial sediments, the cover of Bolders Bank Formation is nearly complete (Cameron *et al.*, 1992).

Of the early Quaternary deltaic deposits, only the Winterton Shoal and Yarmouth Roads formations are exposed at seabed. They have not been sampled in the area, although they are known (from sampling elsewhere) to comprise mainly sandy sediment, and have been identified from their seismic signature alone (Tappin, 1991). Middle-upper Pleistocene sediments are represented by the Swarte Bank, Sand Hole, Egmond Ground, Eem, Bolders Bank and Botney Cut formations. They were laid down in both glacial and interglacial environments.

The Swarte Bank Formation is Anglian in age and records the first unequivocal record of invasion of ice into the southern North Sea Basin. It infills a fan-like array of tunnel-valleys up to 12 km wide

and 450 m deep that are cut into the Early Pleistocene deltaic deposits and underlying bedrock (Figure 2.3.4). Where sediment is preserved, the valleys contain three sedimentary members. The basal member is a chalky till comprised of stiff, grey diamicton with, in some instances, lenses of coarse-grained glacio-fluvial sand. The middle member is the most dominant and formed of stratified, stiff, grey, unfossiliferous, glaciolacustrine mud that records an upward transition into marine clay with a benthic foraminiferal assemblage, characteristic of shallow waters that at times were completely frozen. The uppermost member comprises marine interglacial sediment.

The origin of the valleys has been subject to controversy, but their scoop-shaped form indicates a most likely formation from subglacial



melt water under hydrostatic pressure (Ehlers *et al.*, 1984; Boulton and Hindmarsh, 1987). Wingfield (1990), however, proposed that they are the result of Jökulhlaup, catastrophic floods of melt water produced by a breakthrough of water at the glacial margin. Recent research by Praeg (2003) on the Swarte Bank Formation in the Humber REC area using 3-D seismic volume demonstrates that the valleys are of subglacial origin; initially cut by subglacial rivers and subsequently infilled with sediment as the ice sheet retreated. Ostensibly, this observation invalidates the catastrophic origin hypothesis.

The stratigraphic position of the Swarte Bank Formation, sandwiched between the Cromerian complex, Yarmouth

Roads Formation and sediments with interglacial, Hoxnian fossil assemblages (Tappin, 1991) supports the late Anglian to earliest Hoxnian age (Anglian of Gibbard, 1991). The Formation is the only offshore relic of the of the Anglian glaciation. If the interpretation of the sub-glacial origin of the valleys is correct, then a line joining the present southern termination of each valley approximates the minimum southern limit of a major still stand of an ice sheet at that time (Huuse and Lykke-Andersen, 2000) (Figure 2.3.4).

Following the decay of the Anglian ice sheet, as the climate ameliorated, rising sea level, combined with continuing tectonic

subsidence led, during the Hoxnian, to the re-establishment of a shallow sea in the Humber REC area. The result was the deposition of the Sand Hole and Egmond Ground formations. The Sand Hole Formation is entirely confined to a bowl-like area around the Silver Pit (in which it is exposed at seabed), in the west of the Humber REC area (Figure 2.3.2). It is up to 20 m thick and in BGS borehole 81/52A comprises 14 m of laminated clay which elsewhere in the vicinity yields abundant dinoflagellate cysts and a rich diverse assemblage of interglacial, shallow marine foraminifera (Fisher *et al.*, 1969). The interpretation is that it was laid down during the early, warm part of the Hoxnian Stage, in a quiet, restricted marine environment.

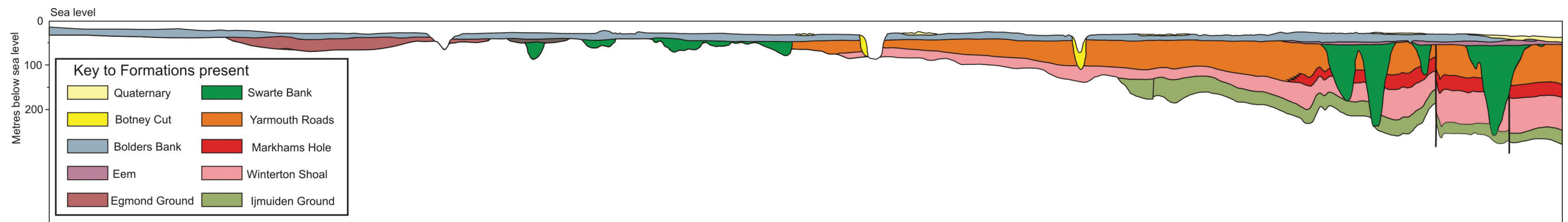


Figure 2.3.3: Quaternary cross section (see Figure 2.3.2 for location).

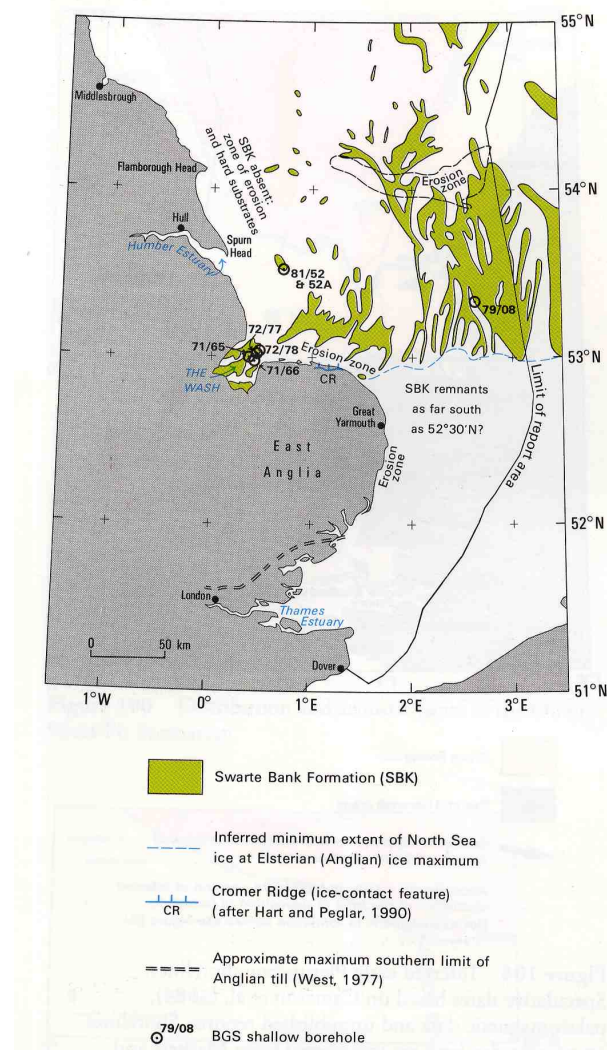


Figure 2.3.4: Distribution of the Swarte Bank Formation (Cameron *et al.* 1992).

Wolstonian glacial sediments have not been identified in the Humber area. They were probably removed during the, subsequent, Devensian glaciation. During the next climatic amelioration, as the ice sheets melted and retreated, sea levels rose again and the Eem Formation was deposited; preserved as discontinuous patches in the east of the REC area. The Eem Formation overlies the Egmond Ground Formation, from which it is hard to distinguish on seismic records because of their similar characters (Figure 2.3.3). The two formations are also lithologically alike. Where positively identified in boreholes, however, the Eem Formation comprises up to 20 m of marine, shelly sand, that westward pass into muddy sandy mud, which is more intertidal in character.

During the most recent late Devensian glaciation, as the ice readvanced, sea levels fell, and the Humber area was again subaerially exposed. At this time the Bolders Bank Formation was laid down. As the last glacial deposit, it is the best preserved and most widespread (Figure 2.3.2). The Bolders Bank Formation on seismic records has a chaotic to poorly ordered, internal character. Where internal seismic stratification is present, this is imparted by sandy beds. The Formation has been sampled in numerous boreholes and short (metres to centimetres) cores. It is characterised by reddish to greyish brown, stiff, diamicton, that in places possess distinct, commonly arenaceous, layering, and deformational structures. The majority of pebbles, of which chalk is the most conspicuous, are derived from the sedimentary rocks of eastern England (Cameron *et al.*, 1992). The pebble content tends to diminish eastwards. The Formation is up to 25 m in thickness

(Cameron *et al.*, 1986; Tappin, 1991). Based on both seismic character and micromorphology, the Formation is interpreted as a composite of subglacial and supraglacial deposits. It has many similarities, and is almost continuous with the diamictons of Hunstanton and Holderness (Cameron *et al.* 1992). The base of the Formation is marked by a high-amplitude reflection that is planar or gently undulating. In places this reflection is interrupted by the basal reflector of the younger Botney Cut Formation (Figure 2.3.3).

Off Holderness, the basal till reflection lies up to 32 m below sea level, and slopes gently eastward to the median line, where it attains a depth of about 55 m. In the east, the Bolders Bank till overlies the Egmond Ground Formation formation or older deposits. The gradual eastward slope is probably due to a combination of basinal subsidence and differential glacioisostatic uplift in the west that followed the retreat of the Devensian ice sheet.

Towards the end of the Devensian, as climate ameliorated and the ice sheets decayed and retreated, the Botney Cut Formation was laid down in scaphiform valleys similar to those of the Swarte Bank Formation. The valleys are within and disposed roughly radially to the outer limits of the Bolders Bank Formation. They are less than 80 m deep and up to 8 km wide, smaller than those of the Anglian glaciation (Swarte Bank Formation). They were formed through the same, subglacial, process, and the smaller size is probably due to a thinner ice sheet. In boreholes the Formation comprises stiff, reddish brown diamicton, similar to that of the Bolders Bank Formation. An upper member is composed of soft to stiff, laminated, sporadically pebbly, glaciolacustrine to

Humber REC Study Area

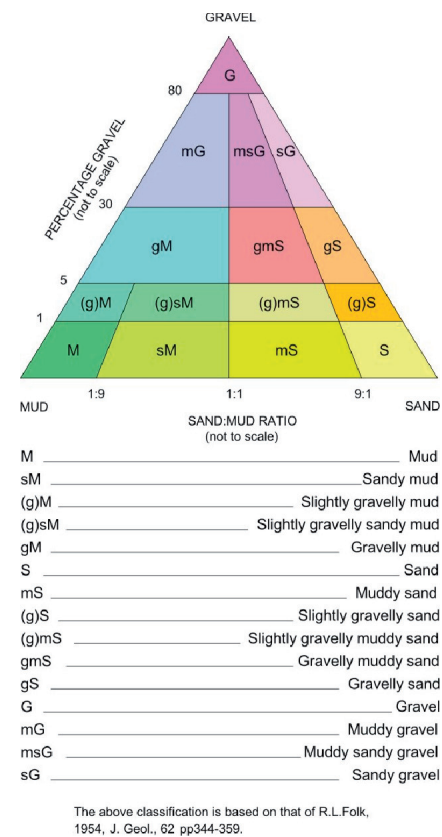
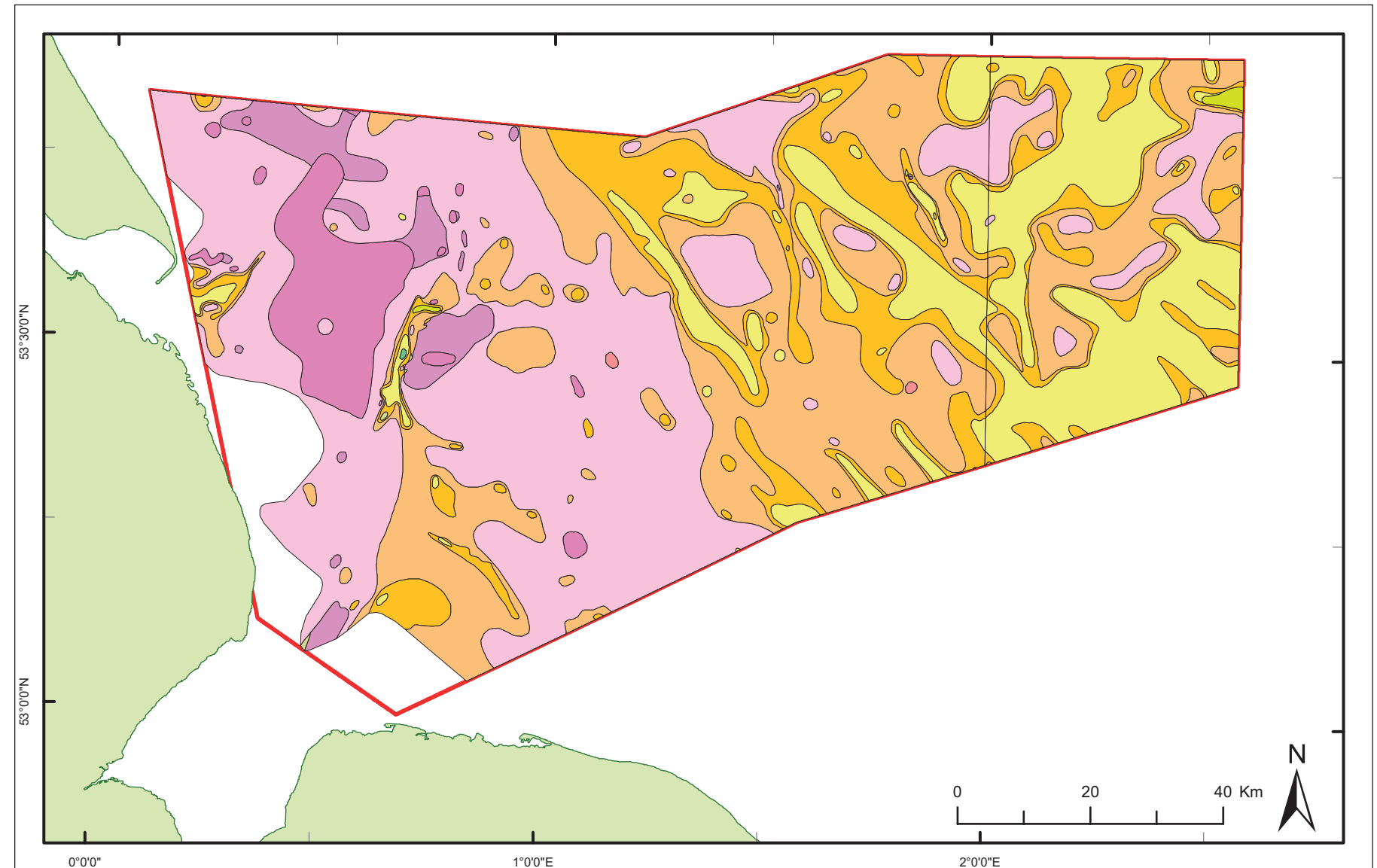


Figure 2.3.5: Distribution of seabed sediments Humber REC (Folk, 1954; Harrison *et al.*, 1987; Balson, 1990; Pantin, 1991).



glaciomarine mud, commonly with the same distinctive reddish brown tints as the Bolders Bank Formation. The valleys may also be infilled with coarse, gravelly, sediment. Some of the valleys form the bathymetric deeps e.g. the Silver Pit, that are such a prominent feature of the REC area. The absence of sediment infill within these deeps is poorly understood, largely because many other glacially eroded valleys are sediment filled with the Botney Cut Formation.

2.3.3 Holocene (Mobile) Sediments

In the early Holocene, with rising sea levels offset by regional isostatic uplift, deposition of glaciomarine mud in troughs and

valleys gave way to intertidal mud, silt and peat of the Elbow Formation, heralding the return of fully marine conditions to the area. It was possibly that at this time, if all the valleys/deeps were indeed sediment filled, this sediment was eroded and removed by the strong tidal currents (Proctor *et al.*, 2001).

Within the REC area Holocene sediments generally form a thin veneer over Pleistocene or older formations. Exceptions are where there are tidal sand banks and large sand waves. Seabed sediments range mainly between sand and gravel. Figure 2.3.5 is a superficial sediment distribution map of the Humber survey area, produced by the BGS before this REC project. The map is

based on particle size analysis of Shipek grab samples classified according to a modified Folk classification scheme (Folk, 1954; Pantin, 1991; Long, 2006) designed to relate the mobile sediment to current strength at time of deposition.

Generally, gravel-rich seabed sediment is more common in the western part of the survey area, whereas sandy sediment is common in the east. Most sediment is mainly derived from reworking of Quaternary deposits with a limited contribution from modern fluvial sources. The main control on present sediment distribution was the sea level rise that took place at the end of the last glaciation.

2.4 Active Sedimentary Processes

Once eustatic sea level had stabilised, the mobile surface sediment cover we see today was established and attained dynamic equilibrium with the present wave energy and tide climate. The bed forms now present are the result of the active marine processes reworking and depositing the sediment available. Sediment delivery patterns in the area are complex, with driving forces varying over different time scales: tidal, seasonal and flood pulses (Dyer *et al.*, 1971). In the southern North Sea sediment transport is mainly a function of suspension-ready sediment availability, rather than hydrodynamic conditions (Williams *et al.*, 1998).

Bed forms are both relict (and therefore inactive) and active where modified by the present tidal and wave regime. Relict features include the deeps and some of the large sand banks that formed during the mid-Holocene post-glacial transgression. Many of the Norfolk Banks probably originated at around 7 800 years BP (Jelgersma, 1979), although it is possible that the near shore banks are more recent. The presence of sediment waves in coarse-grained sediment in the west is probably the result of stronger tidal currents active during lowered sea level.

Sediment mobility is a result of the sediment grains being activated by seabed currents driven by wind-waves, storm surge or tide. In the Humber area the dominant control is the tidal current (Kenyon and Cooper, 2005). Most active bed forms are those formed of sand, although, where currents are strong, particularly nearshore, gravel may also be mobilised. The bed forms present depend upon the current velocity and sediment supply (Stride *et al.*, 1982).

Active bedforms in the area include large sand waves and smaller sand waves (sometimes termed megaripples), sand ribbons and sand patches. In the Humber area the rate of sediment supply is low, and the theoretical passage (as proposed by Stride *et al.* 1982) along the sediment transport path is from furrows and waves in gravel, through isolated sand ribbons and sand streaks parallel to the tidal current, to transverse, horned barchan-type, large sand waves, passing into extensive sand patches with small sand waves (Figure 2.4.1).

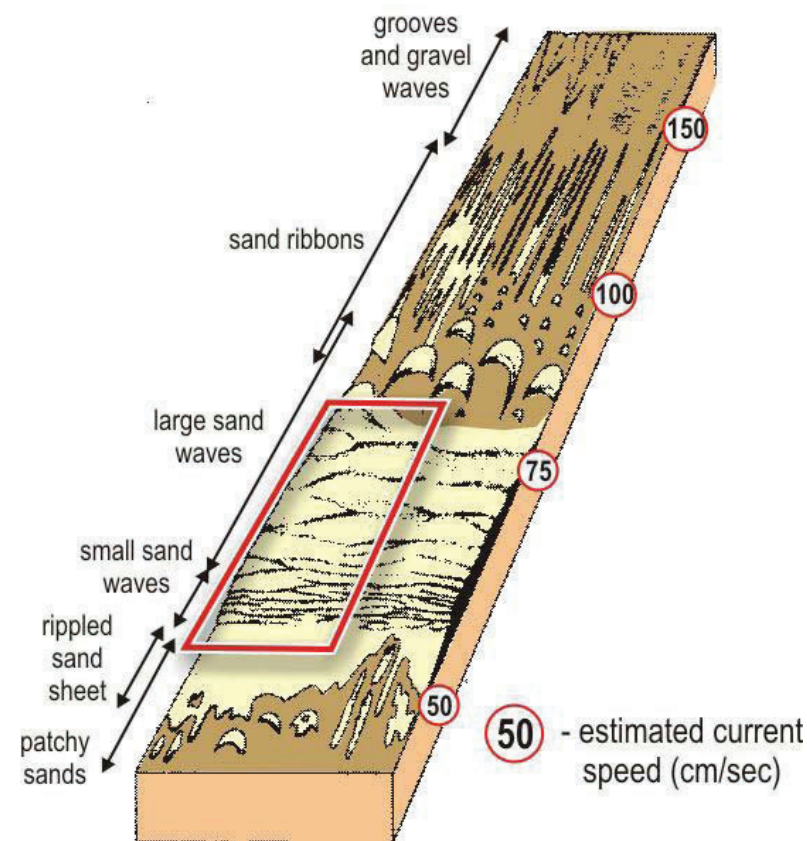


Figure 2.4.1: Theoretical bedform evolution with current velocity in sediment limited regions (Stride *et al.* 1982).

Sand Ribbons and Longitudinal Sand Patches

Sand ribbons are longitudinal features that form parallel or sub-parallel to the net tidal flow. They vary greatly in size and can be up to several kilometres in length and tens of metres wide. Their thickness is small and varies from a few grains up to about one metre. In the Humber area the sand ribbons are typically observed trailing sand ridges or as sand wave trains. They are characteristic of areas with strong, rectilinear tidal currents (75–100 cm/s), and where there is a limited supply of sand.

Longitudinal sand patches are located where the mobile sand layer is not persistent enough to form a continuous sand sheet. Sand patches may be transverse or longitudinal, and are associated with slower current speeds of less than 50 cm/s. They vary in size and can be up to 2–3 m in thickness. In plan view they have varied shapes, from lunate to chaotic, though typically they display sharp edges (Belderson *et al.*, 1982).

Sand Waves

Sand waves typically comprise fine- to medium-grained sand, though 'gravel waves' can occur. They form transverse to the current flow. They form in current regimes where speeds are greater than ~50 cm/s. The variation in the shape of sand waves (Barchan, cat-back, symmetrical, etc.) results from various factors that include, temporary (storm) or cyclical deviations from the dominant current direction, changes in flow amplitude and variations in sediment budget (Allen, 1980; Belderson *et al.*, 1982). They may be symmetrical or asymmetrical, depending on local current conditions. Net directional sand transport in one direction results in wave asymmetry, and the wave travels in the direction of the steepest slope. Internal structure may be homogenous, fining up or down, or cross bedded.

In the Humber REC area, sand wave amplitudes are up to 6 m (Figure 2.4.2). Where sand supply is limited, as for instance in the southwest, isolated sand waves may rest on gravel pavement. Gravel banks are present in the southwest of the Humber area where sandy gravel is dominant. Gravel waves may have lee slope gradients of 34°–41°.

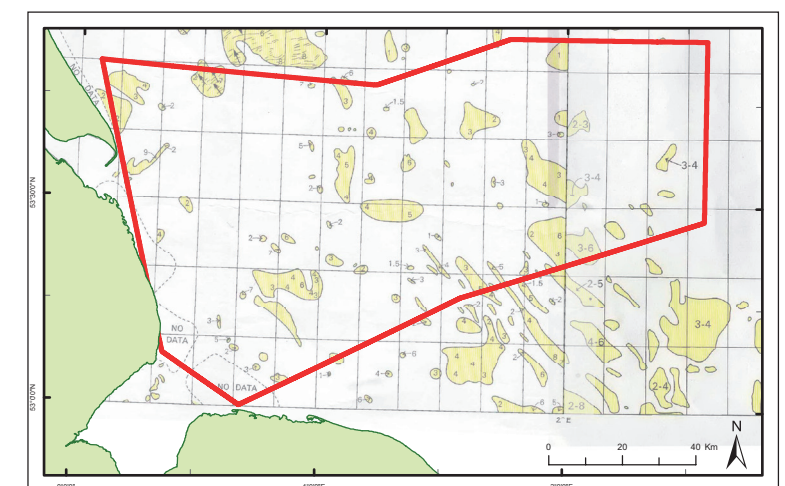


Figure 2.4.2: Sand wave areas in the Humber REC (Harrison *et al.*, 1987; Balson, 1990).

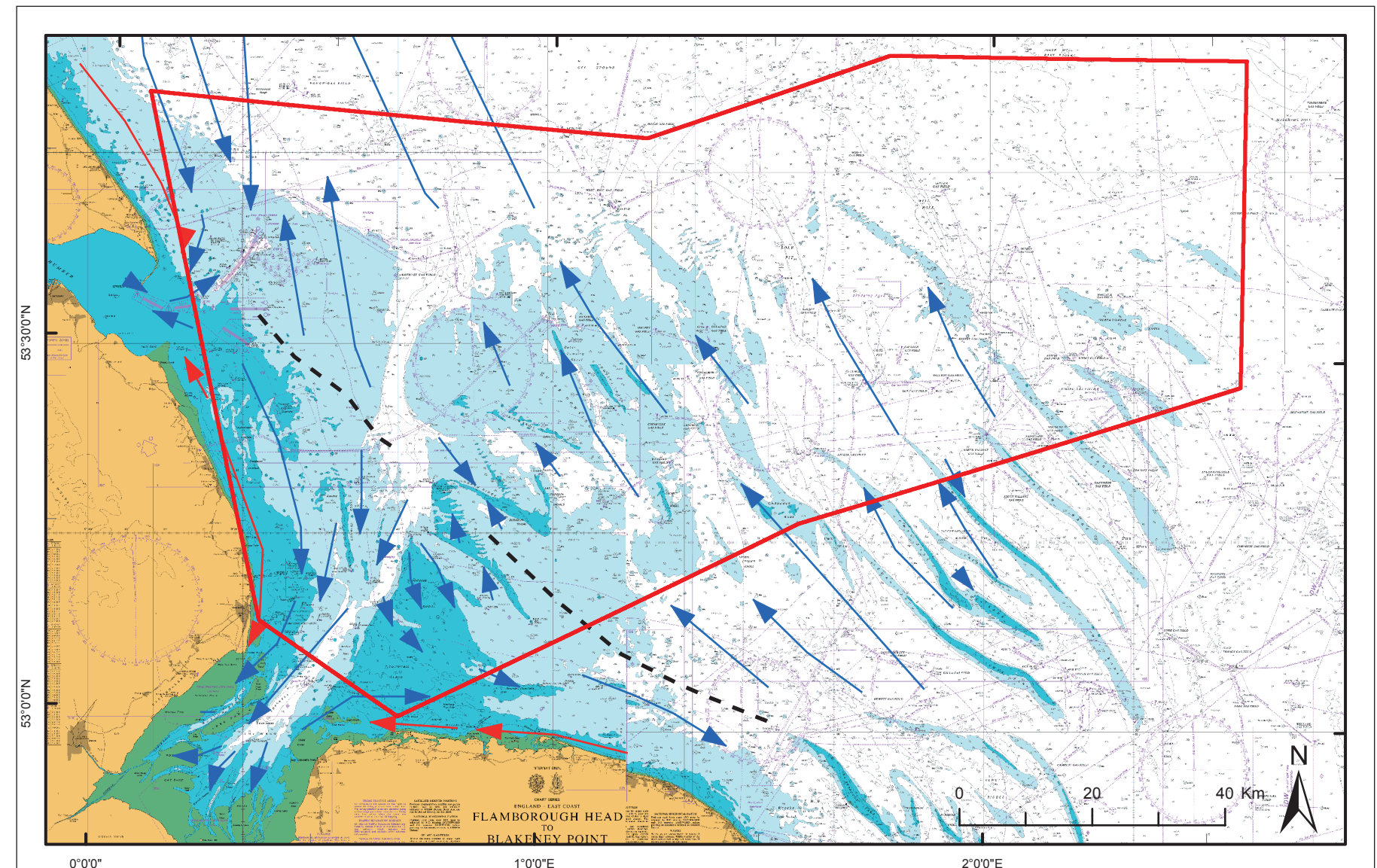
Sand Banks

Groups of parallel banks that are regularly sized and spaced are commonly found on open tidal shelves (Huthnance, 1982; Dyer and Huntley, 1999; Kenyon and Cooper, 2005). They are the

- Humber REC Study Area
Sediment_Transport_Paths
Type
 - - Bedload_Parting
 ➡ Bedload_Transport
 ➡ Longshore_Transport

Figure 2.4.3: Net sand transport paths in the Humber REC (after Kenyon and Cooper, 2005).

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largest bedform on the UK continental shelf, are longitudinal and oriented parallel or subparallel to the dominant tidal flow. In cross section the banks are mostly asymmetrical, with steeper slope gradients consistently on one side, in which direction they may slowly migrate.

Where water depths are less than about 40 m, the crests of active banks may be near sea level, and at these locations the bank tops are flat because of wave action. Larger sand waves are confined to bank flanks. Most banks in plan view display wide upstream (head) ends and narrow downstream (tail) ends (Caston, 1981).

They commonly have a pronounced kink in the upstream direction.

The Norfolk Banks, located off the East Anglia coast, are some of the foremost examples of open shelf linear sand banks in the world (Figure 2.1.1). The northwest ends of these banks extend into the south-east part of the Humber REC area. The banks are mostly parallel to each other. They are mostly formed of sand. They rest on a relatively flat surface at 20 to 30 m depth that is an erosion surface of Pleistocene deposits that are either exposed or covered by thin lag gravel in interbank areas. However, other linear banks,

such as the Outer Dowsing Shoal are found nearer to the coast, and may have a different origin to other banks in the area (Figure 2.1.2) (Evans *et al.*, 1998). The largest bank is Well Bank that is over 50 km long, 1.7 km wide and rises 38 m above the sea floor.

Sinuuous Banks

Sinuuous banks are found in the south west of the Humber REC area; Race Bank/North Ridge/Dudgeon Shoal complex (Figure 2.1.2). Haddock Bank too has a similar morphology and may represent an intermediate stage in the transition between sinuous and linear bank formation. Race Bank/North Ridge/Dudgeon

Shoal also occur along a bedload parting (Figure 2.4.3) which is consistent with the transport paths determined from the sand wave asymmetries around them. These banks exhibit a more graded, shallow relief. Limited sampling shows that they comprise gravelly sediments at the surface. There is no observed pattern of ridge asymmetry. The construction of gravel ridges presumably requires strong bottom currents and a local supply of material i.e. glacial till. Thus, if constructed of gravel, they are likely to be relict features. However, multibeam data over the Race Bank, acquired as part of a recent SEA 5 initiative, indicates that the bank is formed of sand at seabed, and thus may be active (Kenyon and Cooper, 2005).

2.4.1 Sediment Transport Paths

A bedload transport map for the REC area is presented in Figure 2.4.3, modified from Kenyon and Cooper (2005). Tidal currents dominate the bedload transport (van der Molen, 2002). Mean spring near-surface tidal current strength away from the coast is everywhere over 0.75 cm/sec and reaches over 1.7 m/sec in the western, near coastal, part of the area (Figure 2.2.1). In the inshore areas, surge currents are high at between 0.6 and 0.8 cm/sec (Flather, 1987). The surge current's main direction is southerly, a direction which reinforces some bedload transport paths and briefly reverse others.

Modelled maximum bottom stress from tidal currents in the Silver Pit is strong enough to flush out fine-grained sediments (Pingree and Griffiths, 1979; Proctor *et al.*, 2001). The coastal stream transports sand eroded from the Holderness cliffs and from offshore sources southward past the Humber Estuary and into the Wash (McCave, 1979; Motyka and Brampton, 1993). Sand transport is southeasterly on Docking Shoal (new swath mapping data, SEA5 2004). The inshore and offshore streams are separated by a bedload parting that runs from just south of Sand Hole, across the Silver Pit and through the Race Bank/North Ridge/Dudgeon Shoal. The offshore stream is northerly. North of the Norfolk Banks the stream is weakly defined (Kenyon and Cooper, 2005). Transport through the area is mainly southerly and mud is supplied to the Wash and the north Norfolk coast (McCave, 1987). Current measurements in the Wash show that the mean flow is onshore in the Lynn Deep and out along both flanks (Ke *et al.*, 1996).

2.4.2 Sources of Sea bed Sediment and its Distribution

The sediments in the Humber REC area are derived from a number of sources that vary geographically, temporally and with grain size. Much of the sediment now present at seabed was originally laid down in environments very different to those of today. These relict sediments are from glacial and fluvial deposits that were reworked during the early Holocene transgression. In addition, although modern sedimentation rates are relatively low, coastal erosion has also been a major source of sediments throughout the Holocene.

Suspended sediment is mainly sourced from the eroding cliffs of Holderness, which consist of 67% mud (e.g. Lee and Ramster, 1979; Eisma *et al.*, 1981). O'Connor, (1987) estimates that 0.63 x 10⁶ m³ of sand per year is delivered to the sea from the erosion of the Holderness cliffs, and is transported southward by the near shore tidal currents. Rivers supply very little suspended material. The major rivers flowing into the area only input silt and clay grade sediment. Fine-grained sediment, however, may be sourced from the North Atlantic and Baltic, and through the Dover Strait (Eisma and Kalf, 1979; Eisma, 1981). Different sediment grain sizes are now described.

Gravel

Gravel rich sediments (gravel, sandy gravel, and muddy, sandy gravel) dominate the western part of the Humber REC area. They form banks and sediment waves that may be mainly inactive under the present tidal current regime. The distribution of gravelly sediments therefore reflects pre-existing glacial, fluvio-glacial, fluvial and coastal processes. However, the presence of sand waves on the Race Bank suggests active sediment movement (Kenyon and Cooper, 2005). There is a local biogenic contribution to the gravel fraction from mollusc shells (Figure 2.4.4).

Outside of the banks and sand waves, the gravel layer is mostly less than a few tens of centimetres thick and rests on an erosion surface of till of the Bolders Bank Formation or, near the coast, Cretaceous chalk bedrock. In the area of chalk, seabed samples commonly include pebbles of chalk and flint, suggesting that a proportion of the gravel is derived directly from seabed erosion of the underlying strata. Elsewhere, the gravels contain a mix of lithologies that are dominated by Carboniferous sandstone and

limestone. Igneous rocks are considered to have been derived from the Cheviots in north-east England (Veenstra, 1971). In general, the lithological assemblage indicates derivation from Palaeozoic formations of northern England and southern Scotland.

The gravels probably arose as lag deposits that were derived from moraines or glacial outwash fans (Robinson, 1968; Veenstra, 1971) parts of which may remain as topographic features or shoals that reflect the successive limits of the Devensian ice sheet as it retreated northwards (Robinson, 1968). A small proportion of gravel sized sediment may also have been derived from coastal erosion of Devensian till (McCave, 1973; Madgett and Catt, 1978; McCave, 1987; O'Connor, 1987). Gravel derived from modern erosion along the coast between Spurn Head and Flamborough Head is transported southwards by longshore drift to form the sand and shingle spit of Spurn Head; as well as perhaps offshore into the area of the Binks (Figures 2.1.1 and 2.1.2) (De Boer, 1964).

Although most seabed samples indicate that the ridges and banks in the southwest of the Humber area (e.g. Race Bank) comprise gravelly sediments, these may be unrepresentative as there may be only a thin layer of gravelly sediments over a sand core. The sand waves identified on Race Bank by Kenyon and Cooper (2005) may indicate that it is active. The formation and activity of these sinuous banks features is not well understood, but if they are comprised of gravel, they formed under a regime of stronger bottom currents than those of today.

Sand

Sandy sediment is more common in the centre and east of the Humber REC area (Figure 2.3.5), where it forms linear banks that are up to 20 m above the surrounding sea floor, sand waves (Figure 2.4.2) and undulating seabed. The mean grain size of the sand fraction is mainly medium, with coarser grain sizes in the near shore areas (Figure 2.4.5). Fine-grained sand occurs at the mouth of the Humber. Very fine-grained sands are found mostly within the deeps. Coarse-grained sands are limited to areas of tidal current winnowing, for instance along the southern North Sea bed-load parting (Figure 2.4.3). Tidal currents decrease in velocity to the north, and increase to the south of this line of sand transport divergence. Consequently, sand grain size generally decreases northward, but coarsens southward of the bed-load parting (Stride, 1989). Data from the BGS Spurn Sea Bed Sediment Sheet

(Balson, 1990) show that in the central part of the Humber area, sands are typically poorly sorted, but better sorted material is found within the sand banks and in the north (Figure 2.4.6).

The presence of sand waves indicates mobility of the sediment under the present hydrodynamic regime and their distribution relates to modern transport processes.

The heavy mineral content of the sand shows significant geographical variation (Baak, 1936), indicating that sources are varied and include fluvioglacial or fluvial deposits which were deposited before the area was inundated by the sea. The presence of quartz grains of aeolian origin, suggest derivation from aeolian deposits of Devensian age (Cailleux, 1942). At present, the main source of sand is from coastal erosion.

Mud

Muddy sediment in the report region is restricted to a small area in the north of the Silver Pit and Markham's Hole in the northeast (Figure 2.3.5). The large depression of Markham's Hole is believed to have acted as a sediment sink since the early Holocene (Zagwin and Veenstra, 1966; Eisma, 1975), although it is not clear how much of the Holocene infill was deposited as intertidal flat sediment prior to the onset of modern marine conditions.

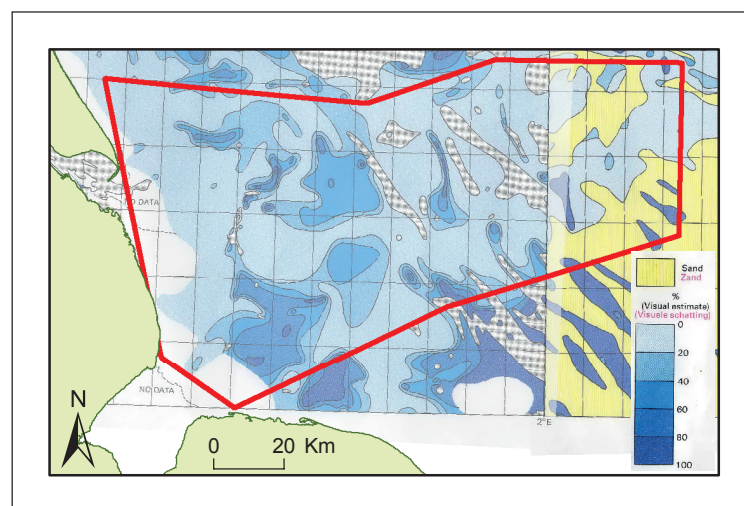


Figure 2.4.4: Biogenic carbonate content of the gravel fraction (Harrison *et al.*, 1987; Balson, 1990).

There is great turbidity in the sea water off the Humber Estuary, with suspended mud reaching >100 mg/l (Eisma and Kalf, 1979). The source of mud is mainly from inflow through the Dover Strait with a supply of 8 to 11.5 million tonnes/year. For the southern North Sea area as a whole, the surrounding rivers of the Rhine, Scheldt, Thames and Humber input 2.7 million tonnes/year, atmospheric dust 0.5 million tonnes /year and coastal erosion 0.3 million tonnes/year (Eisma and Kalf, 1979). The potential input from seafloor erosion is unknown, although McCave (1987) considered it to be unimportant. The volume of mud derived from coastal erosion is also uncertain. McCave (1987) presented a figure of 1.4 million tonnes/year from the Holderness coast and 0.8 million tonnes/year from East Anglia. From coastal erosion of eastern England alone these figures are seven times higher than those of Eisma and Kalf (1979) for the whole of the southern North Sea. Most mud is deposited in nearshore areas and estuaries (Kirby, 1987).

Carbonate

The carbonate content of the sand fraction of seabed sediments in the report area is low, mostly less than 20 per cent (Figure 2.4.7); a figure reflecting the dominance of glacial sediment sources. The calcareous sediment grains may originate from modern, carbonate secreting organisms, or from reworking of early Holocene shell-bearing sediments and older fossiliferous formations.

The water mass in southern North Sea is organically very productive but the preservation potential of much of the biomass is low as the majority is mineralized. The contribution by planktonic organisms to fine-grained sediment is believed to be small (Eisma and Kalf, 1987); the contribution by benthic organisms may be greater, but is localised. Modern, marine, carbonate secreting organisms in the area are dominated by benthic biotas, including molluscs, barnacles, echinoderms, polychaetes and bryozoans. Calcareous foraminifera probably also make a contribution. The distribution of these benthic biotas and their skeletal remains is to a large extent controlled by the nature of the substrate.

In the areas of large, mobile sand waves, echinoderms are abundant. *Donax vittatus* (da Costa) is the most significant mollusc species, with densities of up to 5 or 10 per m². Its' rapid growth and robust shell, makes it an important contributor to the

carbonate fractions in these regions (Wilson, 1982). In gravelly or rocky substrates, encrusting organisms such as barnacles and tube secreting polychaetes may dominate. In general, however, the Humber REC region does not have the carbonate-rich skeletal sediments characteristic of the Western Approaches (Evans, 1990) or to the north and west of Scotland (Pantin, 1991). This is explained partly by the dilution from lithic sediment, but also to the

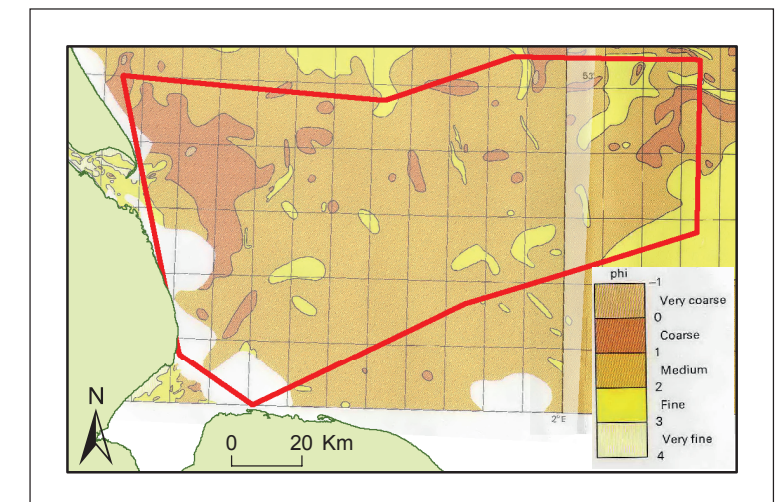


Figure 2.4.5: Mean grain size of sand fraction (phi units) (Harrison *et al.*, 1987; Balson, 1990).

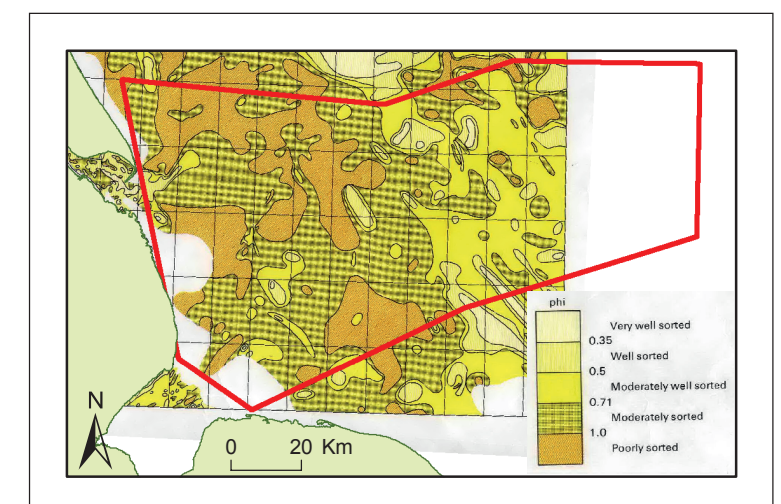


Figure 2.4.6: Spurn Sheet — Sorting of the sand fraction phi units. (BGS Spurn Seabed Sediment Sheet).

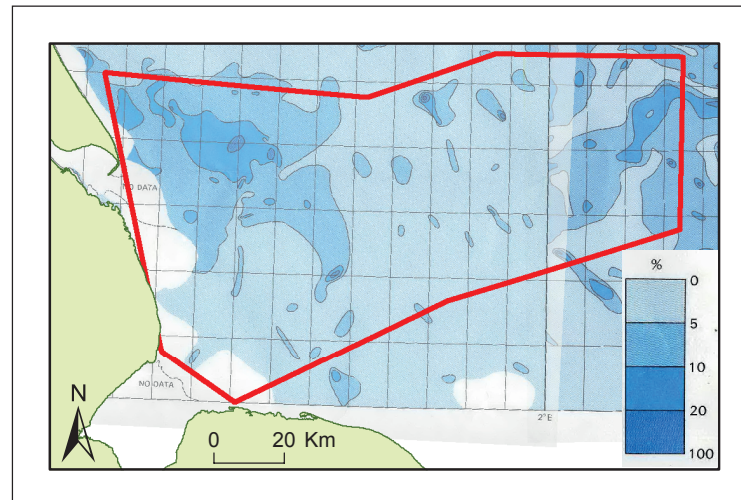


Figure 2.4.7: Carbonate content of the sand fraction. (Note change in scale at 2°) (Harrison *et al.*, 1987; Balson, 1990).

briefier time-span of Holocene marine deposition. The area also has lower carbonate production rates.

Areas of high observed CaCO_3 values in seabed sediments of the southern North Sea commonly relate to derivation from older carbonate-rich sediments. Where chalk is exposed on the seabed, for instance, patchy sediments rich in rounded chalk fragments occur; these may be rapidly abraded by wave and current activity to yield calcareous mud. Similarly, erosion of chalk-rich till may contribute to calcareous mud.

2.5 Marine Archaeology

2.5.1 The Historic Environment — An Introduction

The Humber REC area has a diverse marine historic environment. This environment comprises all forms of physical evidence for human activity in the past, including indirect forms such as palaeo-environmental remains. As such it contains material that ranges in age from the Palaeolithic through to World War II.

Archaeological material contained within the historic environment of the Humber REC is located both on and beneath the seabed, and can be divided into three main groups.

The first of these groups relates to the prehistoric occupation of this region, which covers the period approximately 700 000 BP

to 6 000 BP. The second group is maritime archaeology and comprises ships wrecked within the study area from the prehistoric to the modern period. The final group is that of aviation archaeology that comprises aircraft crash sites.

2.5.2 Prehistoric Archaeology

The marine area of the Humber REC has been repeatedly exposed in prehistory during periods of low sea level. This land area would have contained a variety of environments and landscape features, such as rivers that would have been available for exploitation by hominids. This sea level change clearly had a controlling influence on the terrestrial linkages of Britain in relation to Europe, with rising sea levels occasionally severing land links with Europe.

The knowledge of the archaeological landscape and sea level changes prior to the Late Upper Palaeolithic (700 000 BP to 18 000 BP) is relatively poor for the study area. Any archaeological evidence from these periods is likely to have been adversely affected by repeated glaciations. However archaeological sites such as Happisburg on the East Anglian coast, and the discovery of a mammoth tusk dated to 44 000 BP to the south of the study area (Wessex Archaeology, 2006c Figure 17), illustrate the possibility that material dating to earlier periods may still be present.

The changes in sea level and the archaeological landscape during the period 18 000 BP to 6 000 BP are much better understood than for the preceding periods. The pattern of landscape change during this period has been extensively studied through the work of the ALSF funded North Sea Palaeolandscape Project (NSPP) (Gaffney *et al.*, 2007) (Figure 2.5.1).

The Mesolithic landscape within the study area investigated by the NSPP appears to have been a relatively low lying plain, sloping gently upwards towards the modern shoreline. Several minor topographic changes can be seen at the edge of the NSPP study area which would have provided a degree of higher relief within the Humber REC landscape, but most of the major topographic changes in the landscape are outside of the Humber REC study area to the north.

During the Late Upper Palaeolithic and Early Mesolithic the landscape in the wider region would have been relatively dry and well wooded, and would have been highly attractive to the

hunter-gather populations of these periods. This is illustrated by the discovery of Mesolithic houses at Howick on the Northumbrian coast (Waddington, 2007) and recently Star Carr, in the Vale of Pickering near Scarborough (Milner pers. comms. 2010). The Leman and Ower harpoon point, found offshore between the Leman and Ower Sandbanks (Clark, 1932) (Figure 2.5.2) also illustrates human hunting activity occurring within the study area at this time. Throughout the Mesolithic increasing sea level would have seen the inundation of the northern and western parts of the Humber REC study area, initially forming marshland and tidal flats in areas of more rapid marine inundation. These new environments would have provided enhanced resources to the inhabitants of the landscape and further encouraged occupation. Eventually, however, the landscape was entirely submerged and human occupation ended in the Latest Mesolithic.

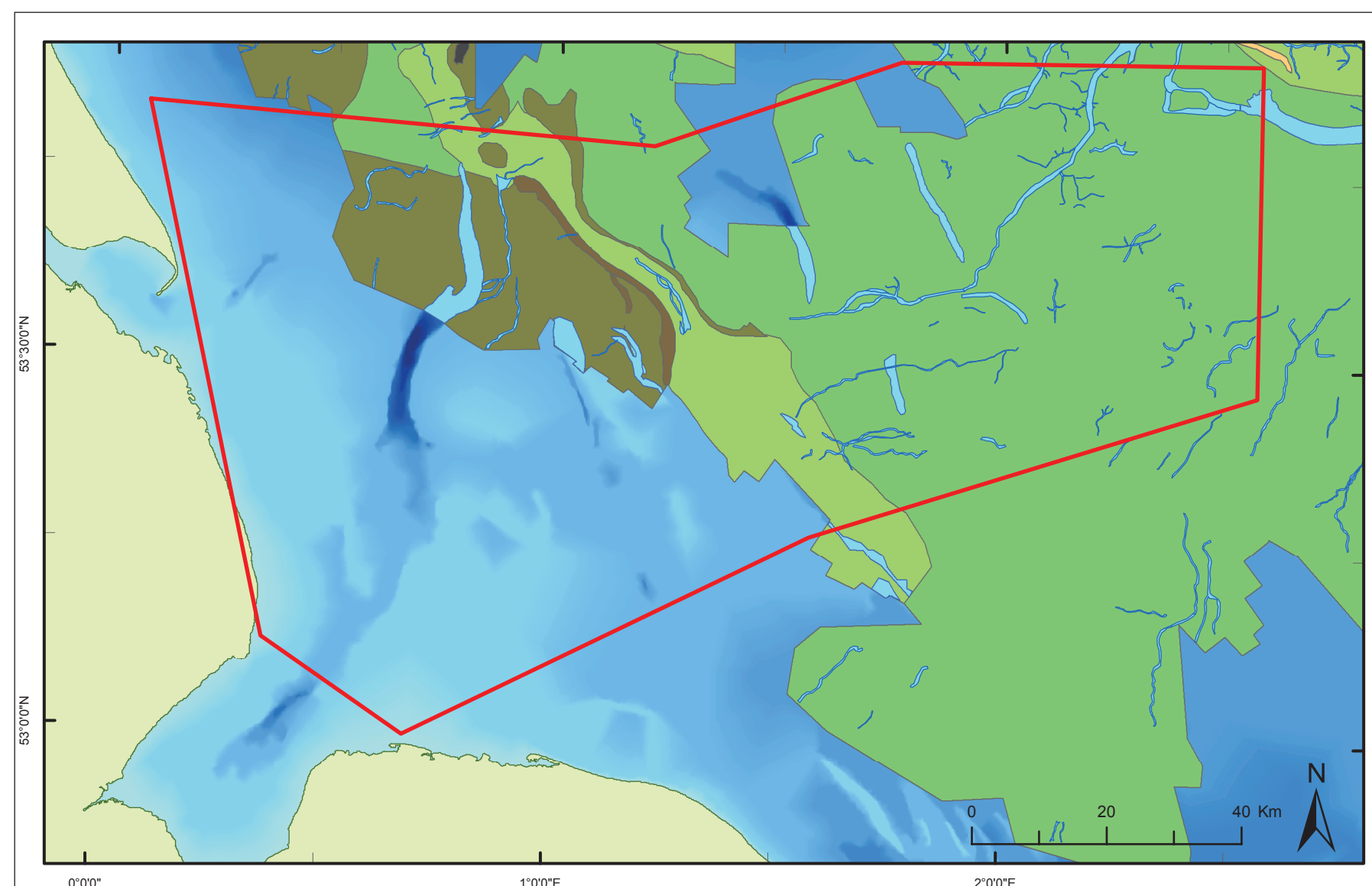
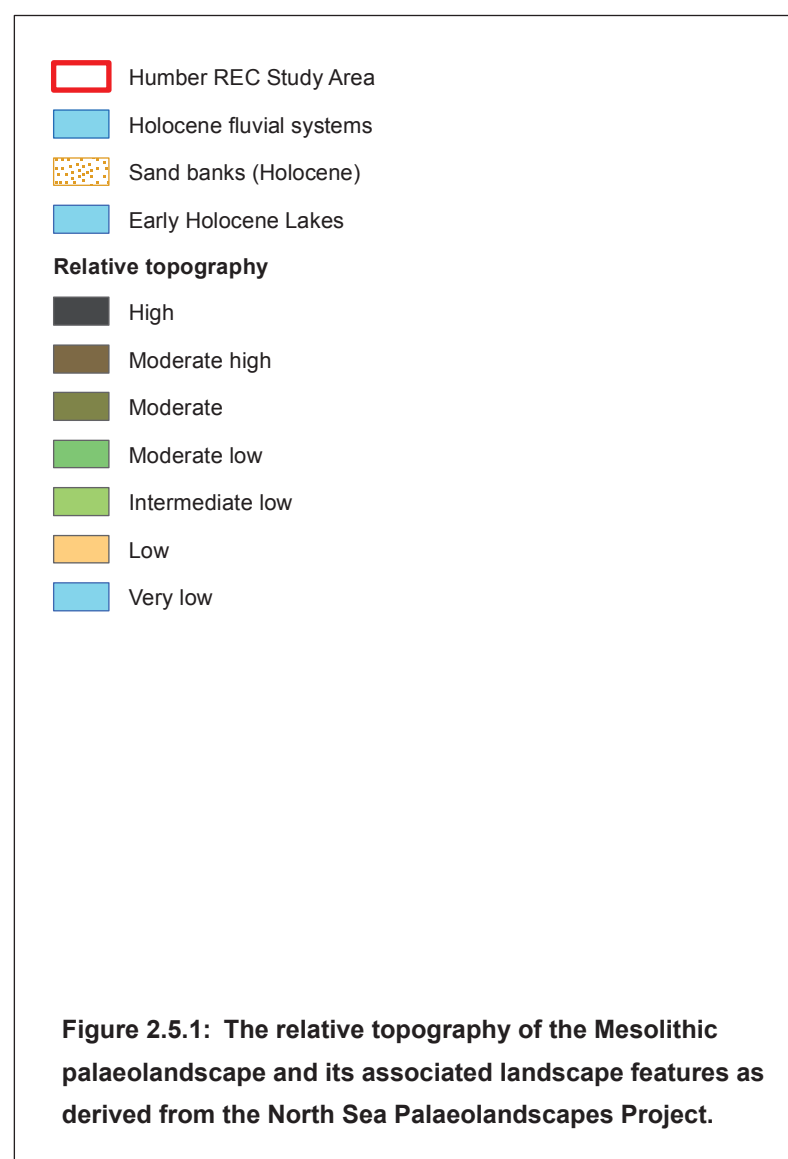
Prehistoric sites and associated archaeo-environmental material from the Late Palaeolithic and Mesolithic periods are most likely to exist within the high archaeological potential zones identified in the south and east of the Humber REC study area. It is probable that these materials may be encountered during any offshore developments within these specific zones. The recovery of this material has the potential to provide insights into patterns of past human land use (Hosfield and Chambers, 2004), and as such developmental activity within these zones offers the opportunity for the recovery of this valuable information. Thus the study area has the potential to greatly improve our understanding of prehistory.

2.5.3 Maritime Archaeology

The study area contains a variety of evidence relating to anthropogenic activity. Archaeological remains along the coast suggest potential for maritime archaeology dating back to the Bronze Age.

The east coast of Britain, notably the Humber estuary, has produced some of the earliest examples of Bronze Age ships and shipping in north east Europe, including the North Ferriby site which produced examples of boats and other possible boat components dating from the early Bronze Age to the Iron Age.

Iron Age maritime activity is indicated by the high concentration of Iron Age gold torcs found to the north and west of Norfolk, which suggests trade in the area around the Wash (Wessex Archaeology, 2007), and Roman maritime activity in the study area



can be inferred from the construction of Saxon Shore forts, such as at Brancaster on the southeastern shore of the Wash, and at Skegness and Brough-on-Humber. Although there is debate on the purpose of these forts, their presence attests both to the threat of invasion by sea, and to the seafaring activities of the Romans at the time (Johnston, 1997; Pearson, 2005).

From the earliest Anglo-Saxon records it is apparent that the Humber estuary provided an important conduit into England, with inland cities such as York connected to the study area by navigable rivers. Anglo-Saxon and Viking fleets are documented as sailing up the Humber. The Humber region is mentioned several times in the

Anglo-Saxon Chronicle, highlighting both its importance, and the importance of seafaring during this period. Archaeological evidence for seafaring is also evident from the well known boat burials, such as at Sutton Hoo, near Ipswich.

The political character of the early medieval period, with loosely united European kingdoms under the authority of the Pope and the Roman Catholic church, indicates a degree of stability that encouraged trade but also spawned religious wars. Both factors had effects on the maritime history of the ship, creating the need for the transport of armies for the crusades and goods for trade (Woodman, 1997, 37).

The earliest wrecks documented within the study area are from the 13th century, a period when international trade, at least within Europe, was flourishing due in part to the Hanseatic League, of which the city of Kingston-upon-Hull in east Yorkshire was associated. The increase in commerce and the upheavals during this period caused by the crusades resulted in the development of the 'full-rigged ship' which emerged around 1550. This vessel construction became dominant, and remained essentially unchanged for three centuries when it finally was superseded by the development of the steamship (Woodman, 1997, 38).

Wrecks documented to the 17th century illustrate the growth of the coal industry, with cargo ships sailing from Newcastle to London. Within the study area, pirates were feared, attacking the coal trade ships. The 18th century saw a continuation and growth of the colliers, as well as international trade both within Europe and further afield. There was a roughly 18 fold increase in shipping tonnage entering the port of Kingston upon Hull between 1716 and 1793. By the early 19th century the town had a volume of traffic around 40 times greater than the preceding century (Kirby and Hinkkanen, 2000, 81). Kirby and Hinkkanen (2000) state that

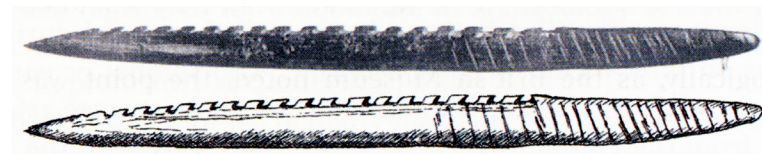


Figure 2.5.2: The Leman and Ower Point — Original Photograph and Drawing by H Muir Evans.

‘the entrance to the port was so overcrowded that it was said that it took less time to sail from St Petersburg than it did to thread through the keels and rafts in the river Hull’.

As well as trade, fishing comprised an important component of the maritime character of the study area during the post-medieval period, specifically comprising trawlers working out of Kingston upon Hull and later, Grimsby.

The study area was witness to much activity during World Wars I (1914 AD–1918 AD) and World War II (1940 AD–1945 AD), with mines and submarine attacks adding to the causes of wrecking incidents at these times. Merchant, fishing and military vessels, including submarines of both Allied and German origin comprise the maritime archaeological remains dating to this period.

2.5.4 Aviation Archaeology

Aviation archaeology comprises the remains of aircraft crash sites, both military and civilian. The majority of aviation sites are from WWII when cities such as Kingston upon Hull and merchant shipping routes in the area were targeted heavily. These sites comprise aircraft of both Allied and German origin.

2.5.5 Recorded Wrecks

The UKHO classify wrecks as live, lifted or dead. A live wreck is considered to exist, a lifted wreck is one that has been salvaged, and a dead wreck has not been detected by repeated surveys and is therefore considered not to exist. There are 396 live wrecks, 15 lifted wrecks, and 164 dead wrecks (dating from the 19th century to present) listed on the SeaZone dataset (derived from data from the United Kingdom Hydrographic Office - UKHO) (Figure 2.5.3). Additionally, there are 150 live obstructions and 27 dead or lifted obstructions, many of which also relate to vessels lost within the area. Roughly 195 of these wrecks and obstructions relate to entries on the National Monuments Record (NMR) which covers a similar date range of wrecks. The NMR further records documented wrecking incidents allocated to ‘named locations’ which were also consulted. These records were also consulted within the offshore study area, as well as up to the coast and in the mouth of the Humber Estuary to assess the potential presence of uncharted wrecks. These wrecks date back to the 13th century, with over 1000 wrecking incidents documented on this dataset within these parameters. The study area therefore has the potential for a wide range of maritime archaeology, from Viking longboats, medieval merchant cogs, industrial colliers, through to steel fishing trawlers, submarines and modern military aircraft.

2.5.6 Historic Sites

There are 3 main laws which apply to shipwrecks, *The Protection of Wrecks Act (1973)*, *The Protection of Military Remains Act (1986)* and *The Merchant Shipping Act (1995)*. Information has been gained from The Office of Public Sector Information website (<http://www.opsi.gov.uk/>), the Marine and Coastguard Agency website (<http://www.mcga.gov.uk/c4mca/mcga07-home.htm>), and the English Heritage website (<http://www.english-heritage.org.uk/server/show/nav.2>).

The Protection of Wrecks Act (1973) allows the Government to ‘designate’ a wreck to prevent uncontrolled interference. Under Section 1, designated sites are likely to be the remains of vessels, or their contents, which are of historical, artistic or archaeological importance. Under Section 2, vessels are designated as being dangerous by virtue of their contents.

In brief, diving is prohibited on wrecks protected under this legislation, and there is an exclusion zone around each site. It is

a criminal offence to do any of the following in a designated area without a licence granted by the appropriate Secretary of State:

- Tamper with, damage or remove any part of a vessel lying wrecked on or in the seabed or any object formerly contained in such a vessel.
- Carry out diving or salvage operations directed to the exploration of any wreck or to removing objects from it or from the seabed, or uses equipment constructed or adapted for any purpose of diving or salvage operations. This is likely to include deployment of remotely operated vehicles.
- Deposit anything including anchors and fishing gear which, if it were to fall on the site, would obliterate, obstruct access to, or damage any part of the site.

It is also an offence to cause or permit any of the above activities to be carried out by others, without a licence, in a restricted area.

Section 1 of this Act is administered by the Department for Culture, Media and Sport. Section 2 of this Act is administered by the Maritime and Coastguard Agency through the Receiver of Wreck.

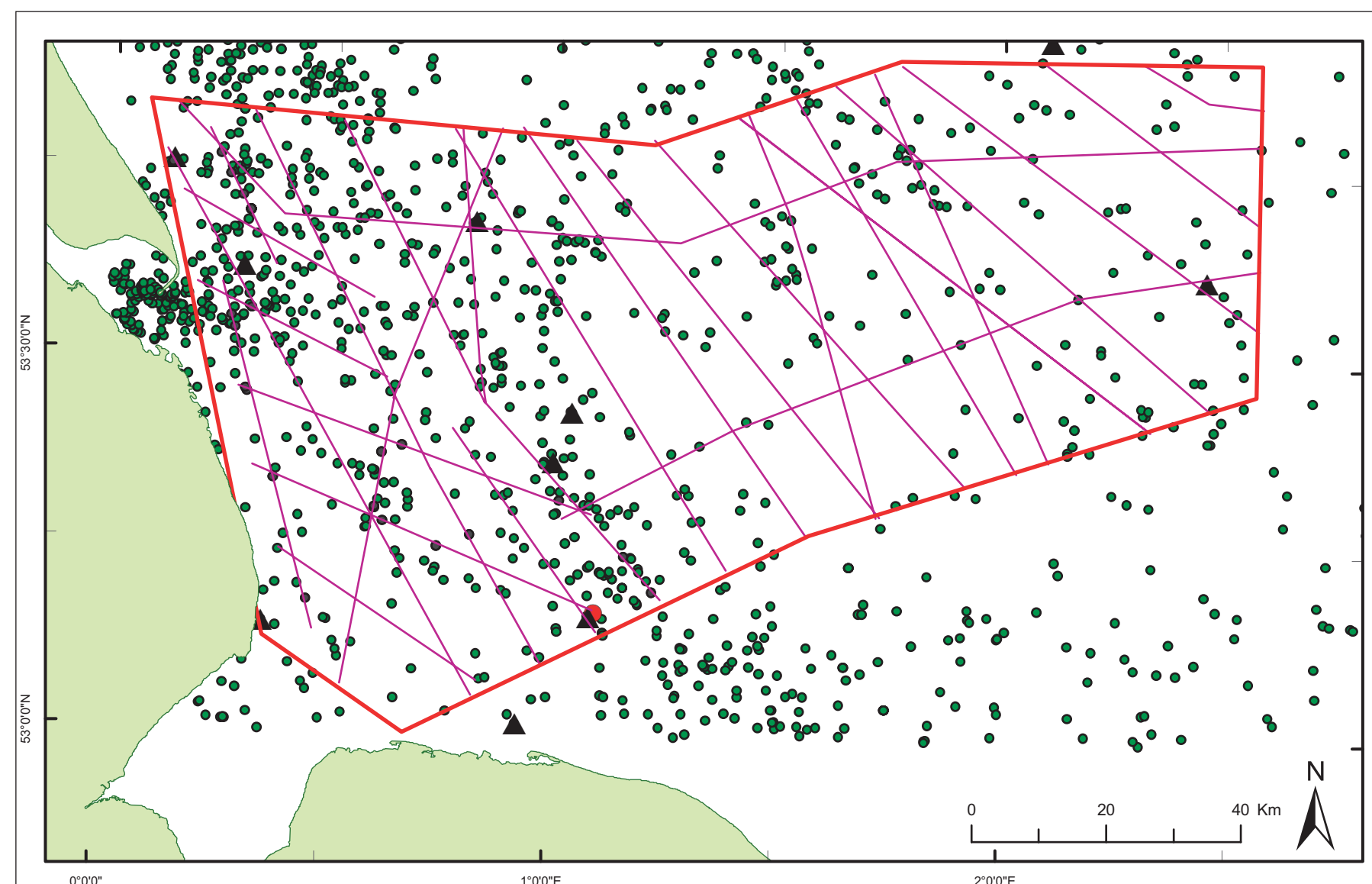
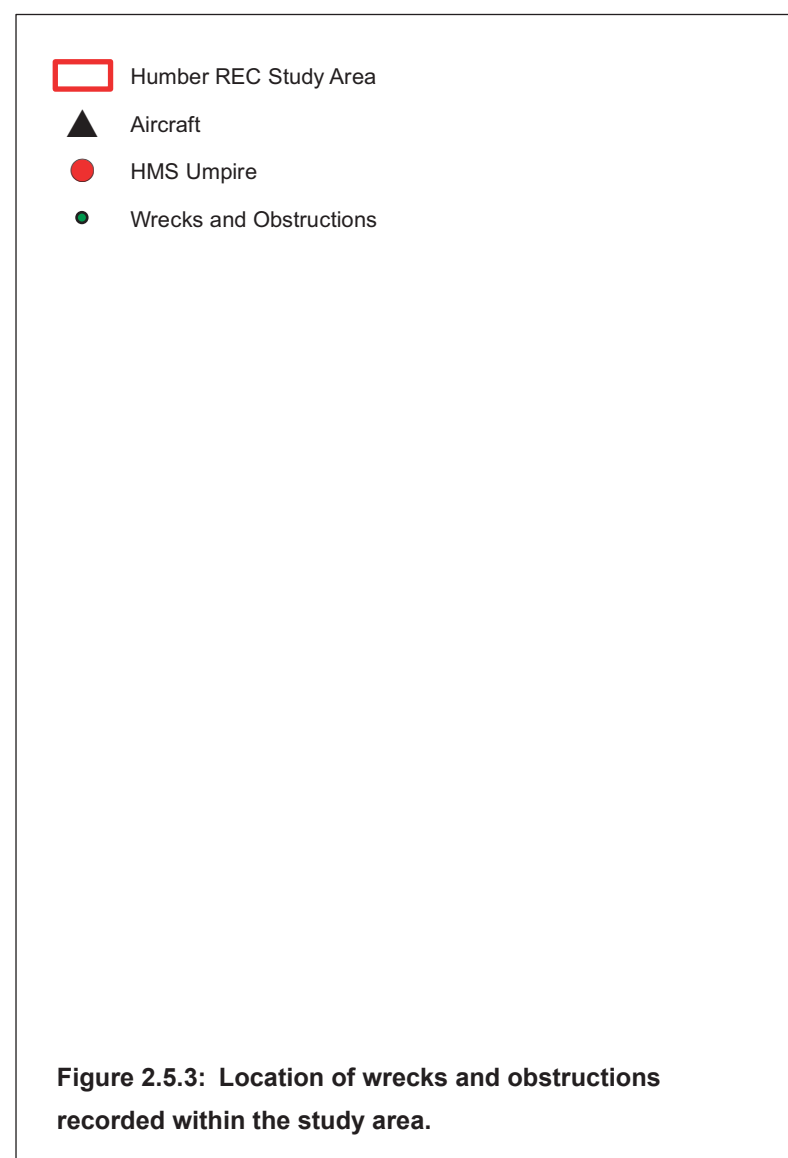
There are no designated wrecks within the study area.

The Merchant Shipping Act (1995), where applied to shipwrecks, states that all wreck material which comes from UK territorial waters, and any wreck which is landing in the UK from outside UK territorial waters must by law be declared to the Receiver of Wreck (Section 236 of *The Merchant Shipping Act 1995*). The act is administered by the Maritime and Coastguard Agency (MCA) through the Receiver of Wrecks. The MCA defines ‘wreck’ as anything which is found in or on the sea, or washed ashore from tidal water, and includes all items which are raised, regardless of age or importance. The finders who report their finds to the Receiver of Wrecks have salvage rights.

The National Heritage Act (2002) enabled English Heritage to assume responsibility for the maritime archaeology in English coastal waters.

2.5.7 Military Sites

The Protection of Military Remains Act (1986) deals with military remains of ships and aircraft. All military aircraft are automatically designated under this legislation. This Act is administered by the Ministry of Defence (MoD).



The MoD can designate an area as a Controlled Site when the precise location is known, and no more than 200 years have elapsed since the loss. Diving, salvage and excavation are all prohibited on Controlled Sites, though licences for restricted activities can be sought from the MoD. There are no controlled sites within the study area.

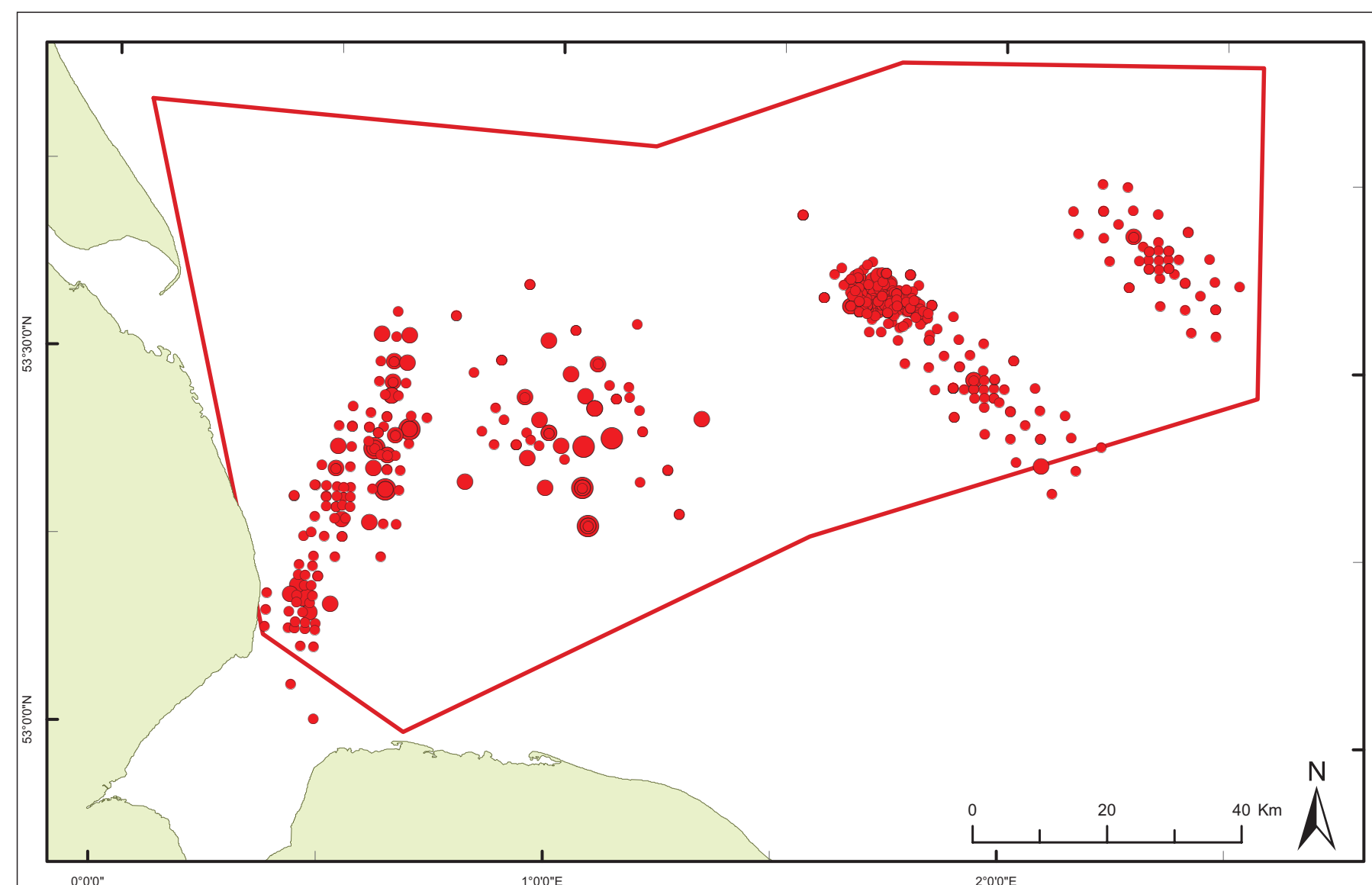
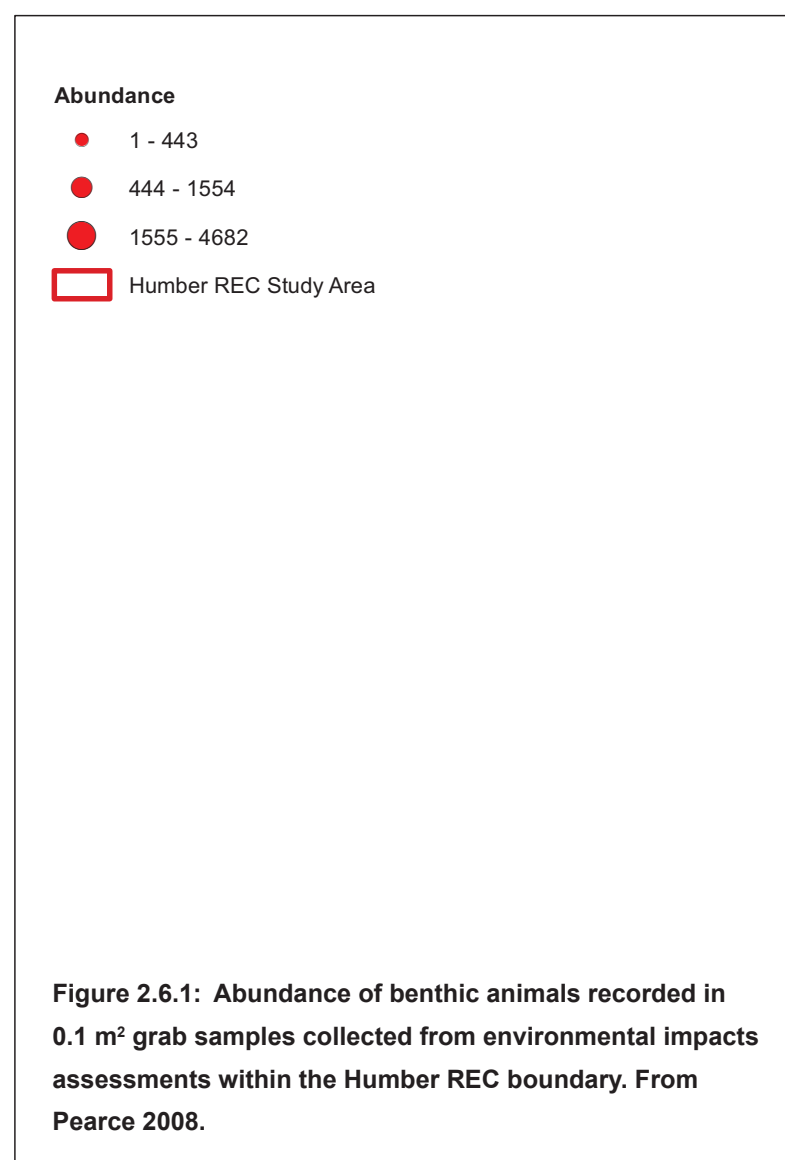
A named vessel can be designated as a Protected Place if the vessel was lost after 4th August 1914, even if the position of the wreck is unknown. Diving is permitted at Protected Places on a 'look but don't touch' basis.

After extensive consultation in 2000–2001 the MoD implemented a rolling program of assessment of all British military wrecks known to have been lost on military service. The first set of designations came into force in 2002, with further statutory instruments designating additional wrecks in 2006, 2008 and 2009 (<http://www.legislation.gov.uk/uksi/2009/3380/contents/made>).

One vessel and eight aircraft within the study area are designated protected places under this act. None of these sites are located within the buffer around the survey lines (see Section 3), or within the areas of detailed archaeological or biological survey.

Protected site - The HMS *Umpire* (UKHO 9266, NMR 907582) was a U-class British Submarine which suffered engine failure while travelling in convoy to operations on the River Clyde from the base at Chatham where she had just been completed. She collided with the Royal Navy armed trawler *Peter Hendriks*. Of a complement of 33 officers and men, 22 lost their lives in the incident.

There are seven aircraft wreck sites, and one possible aircraft wreck site charted on the UKHO data supplied by SeaZone. These include three possible aircraft from WWII, one a German plane and one a Lancaster Bomber, an F3 Tornado aircraft and a Phantom aircraft. Given the unreliable quality of some of the recorded positions, the possibility of these aircraft being within these areas should be considered.



In addition, 72 aircraft are documented on the National Monuments Record, at named locations within the wider study area (including the mouth of the river Humber). Comparison with private datasets suggests these are likely to be only a proportion of the aircraft lost in the area.

2.6 Benthic Communities

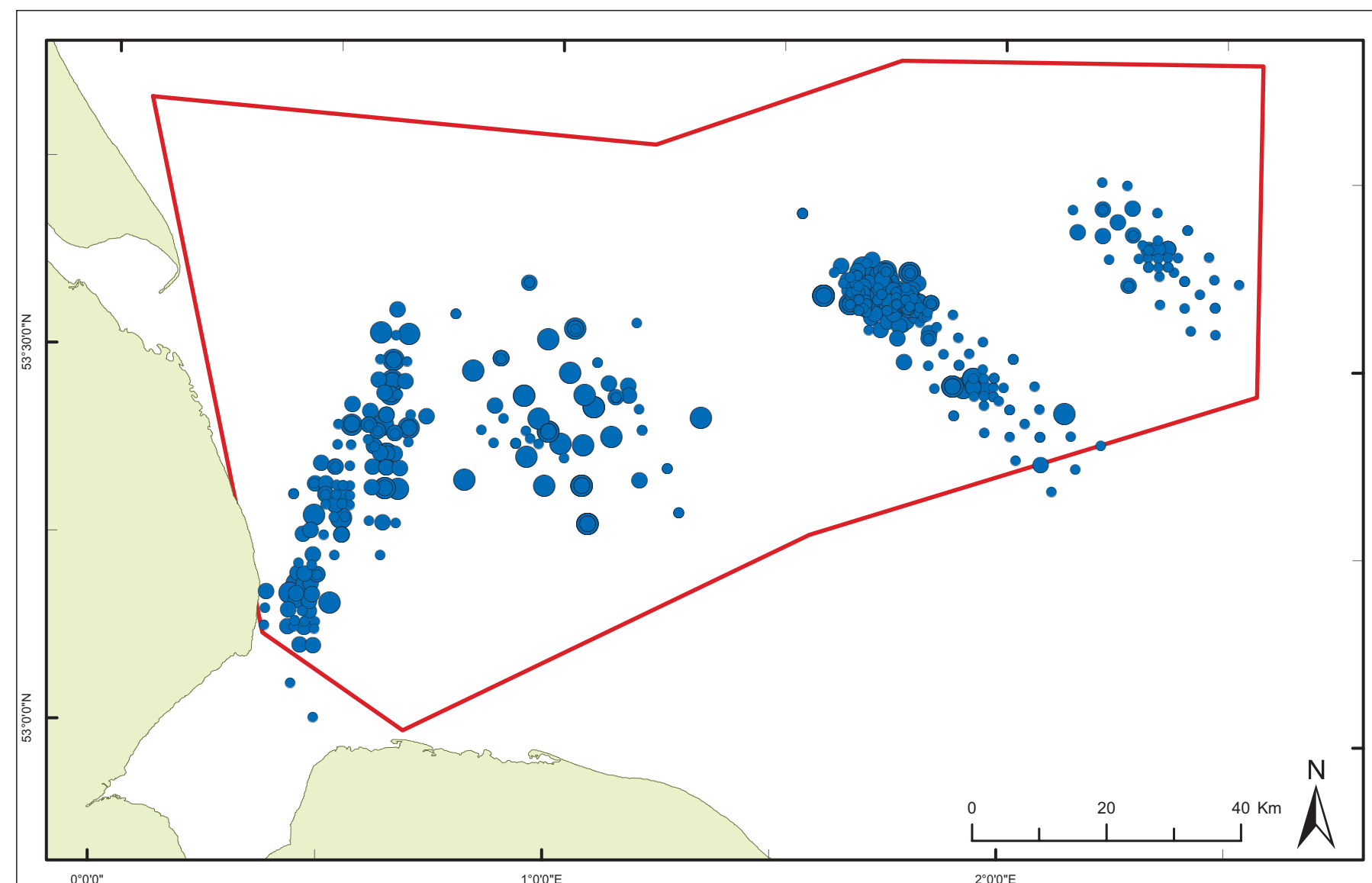
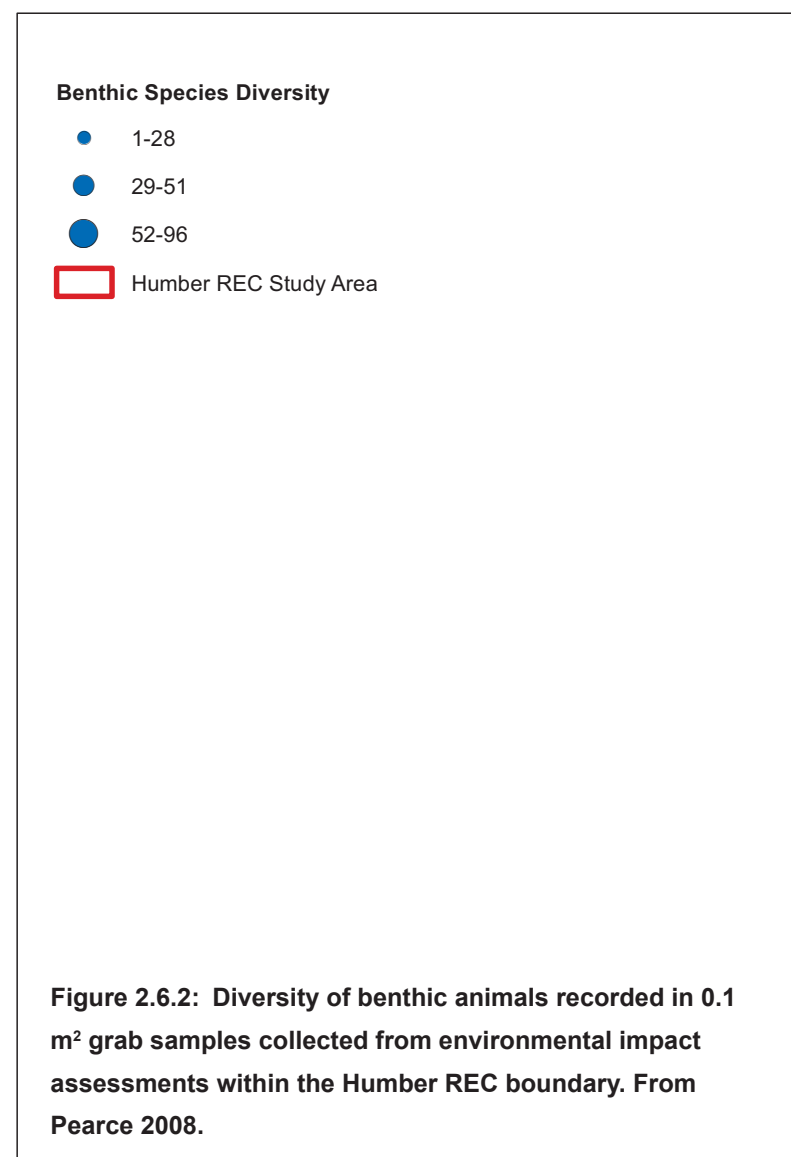
2.6.1 The North Sea

The North Sea has been the subject of extensive marine research in the last century. These studies have made a major contribution to the general understanding of marine benthic ecology and benthic

communities in particular (Petersen C G J. 1914; 1918; Sparck 1935; Remane 1940; Jones 1950; Glemarec 1973). More recently, extensive mapping projects of benthic populations, initiated by the International Council for the Exploration of the Seas (ICES), have further described the benthic communities of the North Sea. These studies are the 1986 North Sea Benthos Survey (NSBS) and the follow-up North Sea Benthos Project (NSBP) carried out between 1999 and 2002 (Kunitzer *et al.* 1992; ICES 2007; Reiss *et al.* 2010).

The results of these studies show that species diversity of both epifaunal and infaunal benthic communities is strongly correlated

with latitude with a northward increase in the number of species (Dyer *et al.* 1983; Kunitzer *et al.* 1992; Heip & Craeymeersch 1995; Rees *et al.* 1999; Jennings *et al.* 1999; Reiss *et al.* 2010; Zulke *et al.* 2001). This latitudinal gradient encompasses a number of influential environmental gradients, in particular a northwards increase in water depth, leading to marked seasonal and regional differences in the vertical structure of the water column between the south and north (Reiss *et al.* 2010; Heip & Craeymeersch 1995). This distribution pattern is also partly determined by the North Atlantic Drift, that reaches the northern portion of the North Sea, and the influx of waters from the English



Channel (Dooley 1981; Frauenheim *et al.* 1989; Heip *et al.* 1992). Higher numbers of both infauna and epifauna also tend to be associated with coarser and gravelly substrata (Kunitzer *et al.* 1992; Rees *et al.* 1999).

The deeper waters north of the Dogger Bank are characterised by arctic-boreal species while the assemblages in the shallower waters to the south are dominated by lusitanian-boreal species (Dyer *et al.* 1983; Frauenheim *et al.* 1989; Kunitzer *et al.* 1992). The central North Sea is an area of overlap of southern and northern species, especially around the 70 m depth contour (Jennings *et al.* 1999; Kunitzer *et al.* 1992).

A longitudinal gradient in diversity also occurs along the southern North Sea with decreasing numbers of species from west to east. This pattern has been attributed to the reduced salinities as well as to the higher climatic and hydrological variability and the influence of human disturbance in the eastern side of the North Sea (Reiss *et al.* 2010; Zulke *et al.* 2001).

2.6.2 The Humber Region

The Humber REC study area lies within the southern North Sea. Although there is a considerable amount of anthropogenic activity taking place in the Humber region (Pearce 2008), to our knowledge

no benthic mapping projects at the scale of the Humber REC have previously been undertaken. The following review is based on data collected by MESL as part of the Environmental Impact Assessment (EIA) process for marine developments in the area (Pearce 2008; Tappin *et al.* 2009) and from North Sea mapping projects that overlap the REC boundary (Callaway *et al.* 2002; Dyer *et al.* 1983; Heip & Craeymeersch 1995; Heip *et al.* 1992; Jennings *et al.* 1999; Kunitzer *et al.* 1992; Rees *et al.* 1999; Reiss *et al.* 2010; ICES 2007; Zulke *et al.* 2001).

The seabed off the Humber Estuary and Norfolk coast has coarse sediments, particularly sands and gravels, and here the number

of species is comparable to the more diverse northern North Sea. This area has high diversity because the 'stony' ground provides attachment for a diverse assemblage of epibenthic species, especially hydroids and bryozoans and also supports rich infaunal communities (Callaway *et al.* 2002; Rees *et al.* 1999). The highest abundances were recorded within the Outer Dowsing area, because of the occurrence of epilithic species such as the sea squirt *Dendrodoa grossularia*, the Ross worm *Sabellaria spinulosa* and the porcelain crab *Pisidia longicornis*. Moving offshore communities were found to be relatively sparse and lower in abundance, reflecting the presence of finer sediments in comparison to coastal sites (Pearce 2008).

The east coast area has also been described as a 'hybrid' region with a sessile fauna typical of the north and free-living species characteristic of the south (Callaway *et al.* 2002).

Benthic Infauna

Several authors have described the infaunal communities at the stations located in the Humber area as typical of coarse-medium (gravelly) sand. Communities are dominated by bivalves such as *Nucula hanleyi*, polychaetes such as *Pholoe* spp. and the reef-building *Sabellaria spinulosa*, brittle stars including *Ophiura* spp. and amphipods such as *Ampelisca typica* (ICES 2007; Rees *et al.* 1999). Other abundant species include the echinoderm *Echinocyamus pusillus* that inhabit the spaces in gravelly substrates exposed to strong wave or tidal action and the polychaetes *Glycera lapidum* and *Polycirrus* spp. (Brown *et al.* 2001; Eggleton *et al.* 2007).

Several surveys, carried out as part of EIAs associated with offshore aggregate extraction and windfarm developments, have been undertaken in the Humber region of the North Sea (Pearce 2008). Although the whole Humber REC study area is not covered these studies also indicate that in general inshore sites have higher abundance and diversity than offshore sites (Figure 2.6.1 and Figure 2.6.2 respectively) and that this trend probably reflects the different nature of the sediment in the two areas. The presence of high species diversity and abundance inshore are strongly related to the occurrence of coarser sediments closer to shore.

Benthic Epifauna (Invertebrates)

The epifaunal assemblages in the 'stony' grounds off the Humber coast were found to support a high number of species despite a general pattern of low diversity in the southern North Sea compared to the north (Rees *et al.* 1999). The presence of coarse sediments in this area provides attachment sites for a diverse assemblage of species with the most frequently occurring being large sessile animals, in particular hydroids and bryozoans. These assemblages are similar to those located at other gravelly habitats in the deeper waters of the northern North Sea. There were also high abundances of *Pagurus bernhardus*, *Liocarcinus holsatus* and *Asterias rubens* in the southern North Sea epibenthos. Jennings *et al.* (1999) suggest that many of these species scavenge on other animals damaged by beam trawls and discarded by trawlers and are quite resistance to trawling themselves (especially *Pagurus bernhardus* and *Asteria rubens*) and suggest that opportunistic short lived species have increased in abundance in the area, while the abundance of long lived Mollusca has decreased.

Demersal Fish

The distribution of fish species diversity in the North Sea does not show the latitudinal gradient, a northwards increase in species numbers, that is observed in the infaunal and epifaunal communities. Rather, there are diversity 'hotspots' of demersal fish with the highest species diversity found near major Atlantic inflows such as the Fair Isles and East Shetland in the north, and the English Channel in the south. These patterns indicate the importance of the immigration of fish species from areas adjacent to the North Sea (Reiss *et al.* 2010). Large scale hydrodynamic variables were found to be important drivers for the structuring of the fish communities. For example, a good correlation was found between fish species distribution and parameters such as bottom water temperature, salinity and in particular summer bottom water temperature (Callaway *et al.* 2002; Reiss & Rees 2007; Reiss *et al.* 2010).

Another peak in diversity occurs in the central North Sea around the 50m depth contour, and this could be attributable to an overlap in northern and southern fish species (Callaway *et al.* 2002; Reiss *et al.* 2010; Reiss & Rees 2007). The REC study area covered in this report is situated within this overlap area.

The highest abundance of demersal fish in the North Sea is also observed in the coastal area of the Humber (Reiss *et al.* 2010). Species particularly characteristic of this region are *Merlangius merlangus* (whiting), *Melanogrammus aeglefinus* (haddock), *Limanda limanda* (dab), *Eutrigla gurnardus* (grey gurnard), *Buglossidium luteum* (solenette) and *Calliominus lyra* (dragonet) (Callaway *et al.* 2002; Reiss & Rees 2007; Reiss *et al.* 2010).

2.7 Marine Mammals

Marine mammals can be divided into two major groups; the Cetacea (whales, dolphins and porpoises) and the Pinnipedia (seals). The Cetacea is further divided into two suborders; the Mysticeti and the Odontoceti. The Mysticeti are the baleen whales and the roquals which possess no teeth, have two external blow holes and feed by means of baleen plates. The baleen, comb like plates which hang from the roof of the mouth, are used to filter large volumes of water sifting out crustaceans and small fish from the water column. The Odontoceti are the toothed whales, dolphins and porpoises which possess teeth and a single blow hole. The Pinnipedia includes the eared seals, true seals and the walrus (Shirihai & Jarrett 2006; Walker & Cresswell 2008).

Marine mammals are observed worldwide although their distribution is fragmented according to their 'preferred' areas. These areas are usually determined by ocean temperature but also by competition with other species (Learmonth *et al.* 2006). Many marine mammals take seasonal migrations determined by prey resources, habitat availability, predation pressures, competition and breeding (Learmonth *et al.* 2006).

The patchy distribution and the elusive nature of marine mammals means they can be difficult to observe and consequently little is known about their behaviour and distribution. It is known however, that the waters surrounding the UK provide year round habitat for numerous species of marine mammals (Afen 2003). Habitat preferences often reflect the distribution of prey species, which are determined primarily by the physical and chemical parameters of the water (Hall, Watkins & Hammond 1998; Learmonth *et al.* 2006). Habitat preferences are also determined by topographic variables such as water depth and nature of and distance to the shelf edge (MacLeod *et al.* 2007).

Marine mammal data collected during dedicated surveys is complimented with *ad hoc* sightings data collected by volunteers and fishermen; however these opportunistic observations can lead to inconsistencies in datasets. Some recordings may also be inaccurate because certain cetacean species can be easily mistaken for others. For example surfacing minke whales can look very similar to sei or fin whales, even fish species such as tuna are often mistaken for dolphins (Walker & Cresswell 2008). Strandings data and accidental encounters also contribute significantly to our understanding of marine mammals although they do not necessarily imply population levels or reflect true distributions (Reijnders & Lankester 1990; Santos *et al.* 2001; Santos *et al.* 2004).

2.7.1 Cetaceans of the Humber Region

Marine mammals that regularly occur in the Humber region (central and southern North Sea) include the harbour porpoise (*Phocoena phocoena*), white-beaked dolphin (*Lagenorhynchus albirostris*), minke whale (*Balaenoptera acutorostrata*), grey seal (*Halichoerus grypus*) and harbour seal (*Phoca vitulina*) (Das *et al.* 2003; Northridge *et al.* 1995).

Marine mammal species that have only been occasionally observed in the Humber region include Atlantic white-sided dolphin (*Lagenorhynchus acutus*), common bottlenose dolphin (*Tursiops truncatus*), common short-beaked dolphin (*Delphinus delphis*), killer whale (*Orcinus orca*), long-finned pilot whale (*Globicephala melas*), and Risso's dolphin (*Grampus griseus*) (Das *et al.* 2003; Evans 2002; Hammond *et al.* 2002a; Reid *et al.* 2003; Reijnders & Lankester 1990; Santos *et al.* 1999). There have also been a very small number of fin whale (*Balaenoptera physalus*) and sperm whale (*Physeter macrocephalus*) observations around the Humber region (Das *et al.* 2003).

Harbour Porpoise — *Phocoena Phocoena*

The harbour porpoise (Figure 2.7.1), *Phocoena phocoena*, the smallest cetacean in the European Atlantic, is the most frequently sighted cetacean in UK waters (Goodwin & Speedie 2008; Reid *et al.* 2003). The North Sea has been reported to represent one of the most important habitats in the world for the harbour porpoise (Das *et al.* 2003; ICES 2008). In 1994 it was estimated that there were 268 000 harbour porpoises inhabiting the North Sea (Hammond *et*



Figure 2.7.1: Harbour Porpoise, *Phocoena phocoena*
© Gardline Environmental Limited.

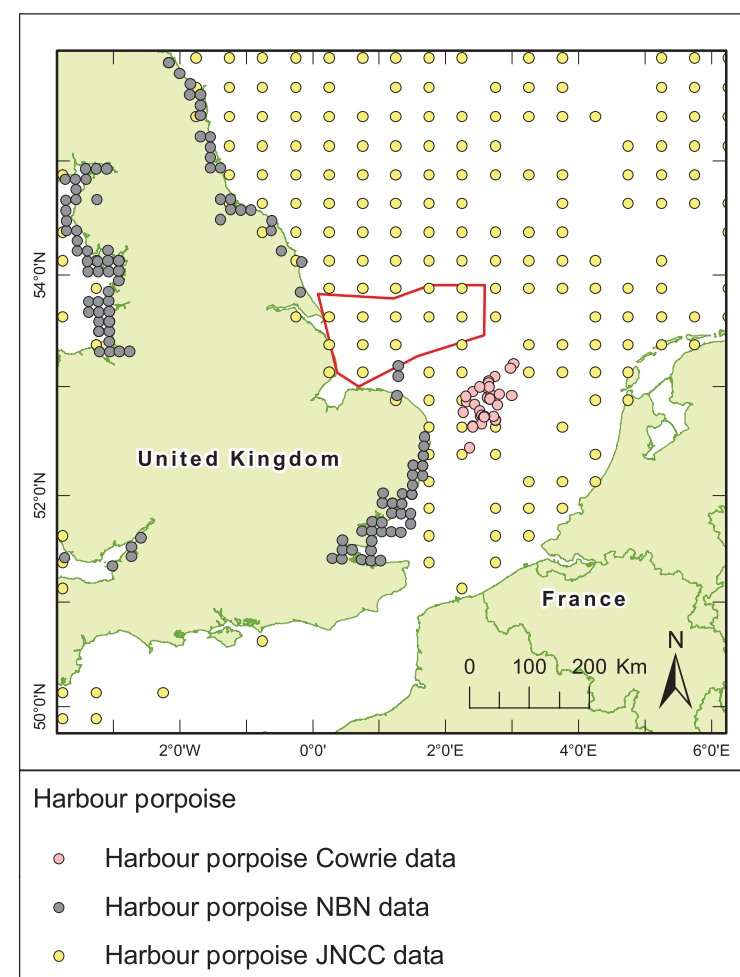


Figure 2.7.2: Recorded sightings of harbour porpoise, *Phocoena phocoena*, in the Humber REC study area (Hexter 2009; JNCC 2003; NBN 2010; Reid *et al.* 2003).

et al. 2002a; Hammond *et al.* 2002b; Reid *et al.* 2003). Porpoises are known to have a shelf tendency (distance to coast or water depth),

preferring coastal waters and depths around 60 meters (MacLeod *et al.* 2007) although deep water sightings are not uncommon (Northridge *et al.* 1995).

Abundance is higher in the southern North Sea than in northern areas, which is thought to be related to prey distribution (Hammond *et al.* 2002a; Hammond 2006; ICES 2008). Evans *et al.* (2003) report that sub-populations may exist in the Irish Sea (Wales), northern North Sea and southern North Sea (Netherlands) (Evans, Anderwald & Baines 2003). Northridge (1995) found two major groupings of porpoises in the North Sea; one to the west of Denmark and another in the deeper waters of the north-western North Sea. Furthermore, Northridge observed a scattered distribution between these groups at the Humber, possibly linking the two groups (Northridge *et al.* 1995). Within the Humber REC study area harbour porpoises are observed off Spurn Head, at the head of the Humber estuary, throughout the year (Figure 2.7.2) (English Nature 2003; Northridge *et al.* 1995).

Historically harbour porpoises have utilised the inland tidal water bodies of the Humber and other adjacent regions. Porpoises were observed in 1876 in the Humber in numbers up to 'four and five hundred' but this was followed by a sharp decline in observations in the early 20th century (Evans 1980). Following recent improvements in conservation legislation and water quality harbour porpoises have increased in number. It was thought that porpoises followed migratory salmonid species with numbers peaking with inshore migrations of salmon. Most studies however, indicate that porpoises prey upon smaller, pelagic fish such as whiting, herring, cod and sand eels (Das *et al.* 2003; Evans 1980; Howes 2008; Santos *et al.* 2004).

In August and September high stranding and sightings of porpoises coincide with the migratory inshore movements of spawning mackerel and herring (Howes 2008). Howes (2008) suggests this is also timed with porpoise breeding and highlights the importance of the Humber estuary as a seasonal nursery. Other studies have also shown that during the calving season the main porpoise distribution is along the western margin of the North Sea between Yorkshire and the Shetland Isles (Northridge *et al.* 1995).

In the North Sea the harbour porpoise is badly affected by bottom set gillnet fisheries (Hammond 2006; Reijnders & Lankester 1990). In the early 1990s the bycatch of Danish gillnet fisheries was approximately 6–7 000 porpoises in the central and southern



Figure 2.7.3: White-beaked Dolphin, *Lagenorhynchus albirostris* © Marine Wildlife Department of Gardline Environmental.

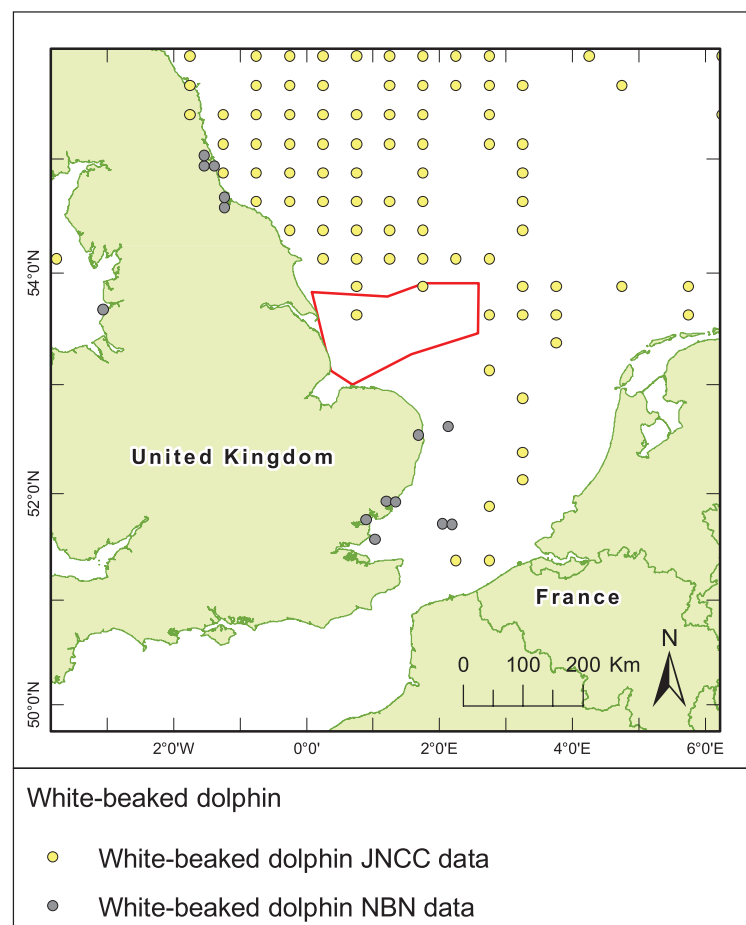


Figure 2.7.4: Recorded sightings of white-beaked dolphins, *Lagenorhynchus albirostris*, in the Humber REC study area (JNCC 2003; NBN 2010; Reid *et al.* 2003).

North Sea (Gislason 1994; Hammond 2006; Vinther 1999). The minimum estimated mortality of porpoises per year is around 5 500 which is believed to exceed sustainable levels and is considered a significant factor in the population decline of this species (Evans *et al.* 2003; Hammond *et al.* 2002a; Reid *et al.* 2003).

As the most common cetacean in the North Sea it is likely that *P. phocoena* is an important predator consuming fish such as herring, mackerel, sandeels, whiting, sprat and cod. There is, however, little information available to assess their ecological importance in the Humber REC study area (Hammond *et al.* 2002b; Howes 2008; Santos *et al.* 2004).

White-Beaked Dolphin — *Lagenorhynchus Albirostris*

The white-beaked dolphin, *Lagenorhynchus albirostris* (Figure 2.7.3) is the most abundant dolphin species to be recorded in the North Sea with population estimates of 7 900 individuals, indicating the North Sea as a major habitat for this species (Hammond 2006; ICES 2008). The white-beaked dolphin is frequently sighted along the eastern coast of the UK (western edge of the central/southern North Sea) (Das *et al.* 2003; Evans & Hammond 2004; Northridge *et al.* 1995) predominantly around Scotland but also as far south as the Thames (Figure 2.7.4) (Canning *et al.* 2008; Evans 1980). Peak numbers of individuals occur off the east coast of England between May–June (Evans *et al.* 2003). *Lagenorhynchus albirostris* is usually seen in pods of around 10–50 individuals, although pods of up to 100–500 animals have been observed in the North Sea (Evans 1980; Reid *et al.* 2003).

The distribution of the white-beaked dolphin is thought to be linked to sea temperature, with larger groups associated with lower temperatures. Therefore, this species may be restricted to the cooler northern areas in the summer months (Canning *et al.* 2008; Weir, Stockin & Pierce 2007). This is reflected in a steadily northward shifting distribution observed over the period of 1992–2003, possibly linked to the effects of climate change (Learmonth *et al.* 2006; MacLeod *et al.* 2005). Northridge *et al.* (1995) found that *L. albirostris* is confined to shelf areas with a general increase in sightings towards land in summer months (Canning *et al.* 2008; Northridge *et al.* 1995). Other factors such as prey density may also influence the distribution of this species (Canning *et al.* 2008; Weir, MacLeod & Calderan 2009; Weir *et al.* 2007). The white-beaked dolphin is said to belong to the 'southern North Sea food-web' (Das *et al.* 2003).



Figure 2.7.5: Atlantic White-sided Dolphin, *Lagenorhynchus acutus* © Marine Wildlife Department of Gardline Environmental.

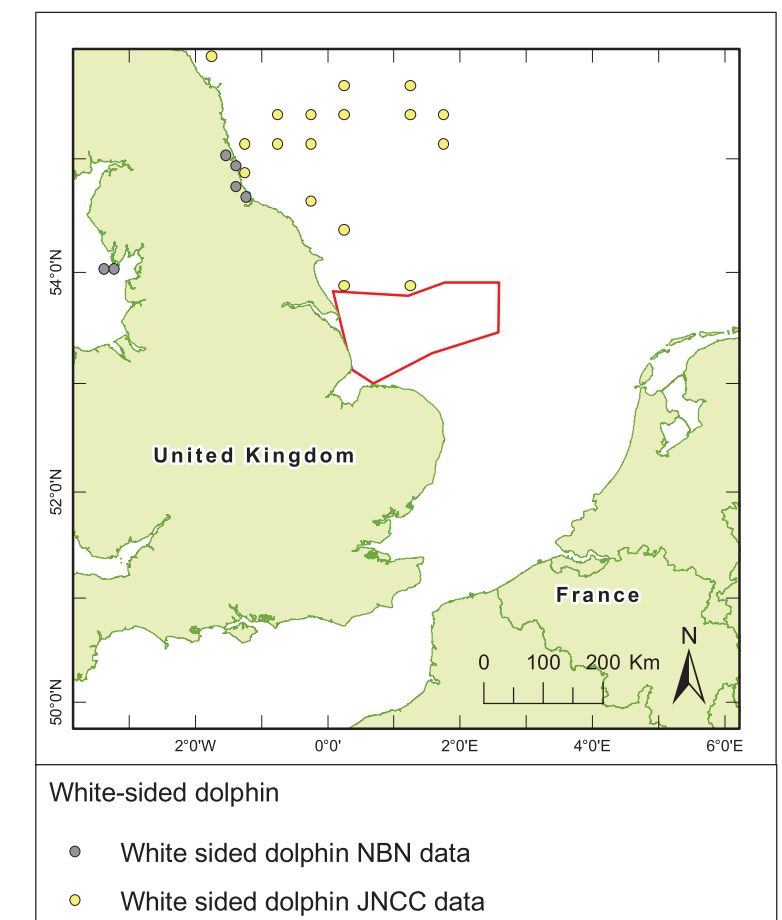


Figure 2.7.6: Recorded sightings of Atlantic white-sided dolphins, *Lagenorhynchus acutus*, in the Humber REC study area (JNCC 2003; NBN 2010; Reid *et al.* 2003).

In the Humber REC study area white-beaked dolphins have been observed in the northern regions of the study site (Figure 2.7.3.).

Canning *et al* (2008) analysed *L. albirostris* strandings data and found a segregation of the sexes in the North Sea. In the months June to September all strandings and sightings were found to be either females or calves (Canning *et al.* 2008; Weir *et al.* 2007). This suggests that females move inshore to give birth in summer months, with males following later (Canning *et al.* 2008).

Atlantic White-Sided Dolphin — *Lagenorhynchus Acutus*

The Atlantic white-sided dolphin *Lagenorhynchus acutus* (Figure 2.7.5) is very similar to *Lagenorhynchus albirostris* and the two species are often observed together in mixed pods (Reid *et al.* 2003). However, the distribution of the two species varies as Atlantic white-sided dolphins prefer deeper, offshore waters around depths of 100–300 meters (Evans & Teilmann 2009; Hammond *et al.* 2002b) and so is less common in the Humber REC study area than the white-beaked dolphin. *Lagenorhynchus acutus* are distinguished from *L. albirostris* by their colouration, possessing a band of yellow or tan along both sides of the tailstock and pale grey flanks with a striking white central blaze (Carwardine 2003; Shirihi & Jarrett 2006; Walker & Cresswell 2008).

The Atlantic white-sided dolphin is reportedly distributed in the northern and central areas of the North Sea and rare in the southernmost region (Evans 1980; Evans *et al.* 2003) although there are no comprehensive population estimates (Evans & Teilmann 2009). Peak numbers of sightings in east England occur between March and September and in November (Evans *et al.* 2003). Evans (2002) reports an occasional distribution around Spurn Head, encompassing the top north-western area of the Humber study area (Evans 2002) however this data is not displayed. *L. acutus* is observed around the northern border of the Humber REC study area (Figure 2.7.6), so it is likely that Atlantic white-sided dolphins pass through the Humber REC study area.

Minke Whale — *Balaenoptera Acutorostrata*

The minke whale, *Balaenoptera acutorostrata* (Figure 2.7.7), is the smallest, most frequently recorded baleen whale in the North Sea (Carwardine 2003; Howes, Boyd & Cutts 1987; Northridge *et al.* 1995) and is thought to be the most important marine mammal in terms of biomass (ICES 2008). Minke whales are usually rather



Figure 2.7.7: Minke whale, *Balaenoptera acutorostrata*
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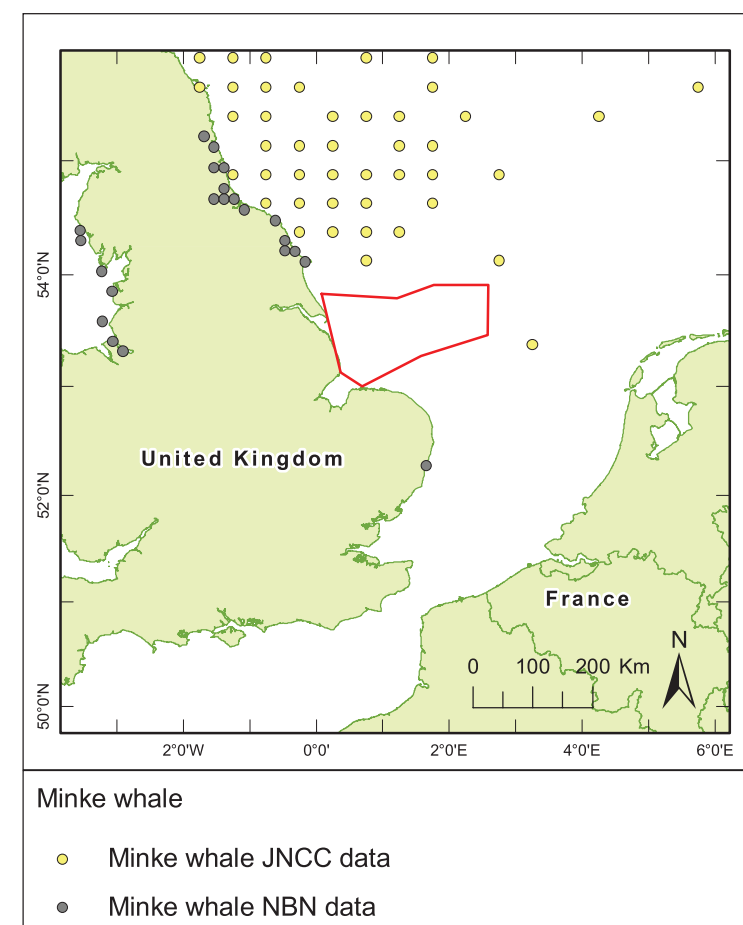


Figure 2.7.8: Recorded sightings of minke whale, *Balaenoptera acutorostrata*, in the Humber REC study area (JNCC 2003; NBN 2010; Reid *et al.* 2003).

solitary although they have been occasionally observed in groups of around 5-15 individuals (Anderwald & Evans 2008).

In 1994 it was estimated that there were 7 200 minke whales around the east coast of Scotland and the central/southern North Sea, an area which encompasses the Humber REC study area (Hammond *et al.* 2002b). Seasonal variability in minke distribution is thought to be related to offshore movements in colder months (Anderwald & Evans 2008; Hammond *et al.* 2002b). Evans (1980) suggests that minke whales migrate north-eastwards of Britain in summer months which coincides with findings from Northridge (1995) who found that minke whales are only observed from May to October in the North Sea (Evans 1980; Northridge *et al.* 1995). *B. acutorostrata* is occasionally sighted around the Humber REC study area (Figure 2.7.8) and many strandings have been recorded (Evans 1980; Howes *et al.* 1987), although these are not illustrated in the figures. Highest sighting rates occur off the Hebrides and down the western edge of the North Sea from the Orkneys to Flamborough Head in Yorkshire (Northridge *et al.* 1995).

Occasionally Sighted Cetaceans

In the North Sea the bottlenose dolphin, *Tursiops truncatus*, is normally distributed around the coastal waters of northeast Scotland although it has been reported on a few occasions near the Humber REC study area (Figure 2.7.9) (Hammond *et al.* 2002b). The common bottlenose dolphin is a robust, rather featureless dolphin with a uniform grey body, a curved forehead and a short stubby beak. *T. truncatus* are strong, acrobatic swimmers that frequently bow or wake ride displaying their very playful behaviour. They are commonly seen in groups of 5-50 individuals (Carwardine 2003; Shirihi & Jarrett 2006; Walker & Cresswell 2008). Whilst the common bottlenose dolphin is known to pass through the Humber region there is no evidence to suggest it holds any special significance for this species.

The Long-finned pilot whale, *Globicephala melas* (Figure 2.7.10), is often associated with the common bottlenose dolphin (Carwardine 2003; Shirihi & Jarrett 2006). *G. melas* is a rare but occasional visitor to the southern North Sea (Evans 2002), seasonal peaks in occurrence for the east of England occur in August (Evans *et al.* 2003).

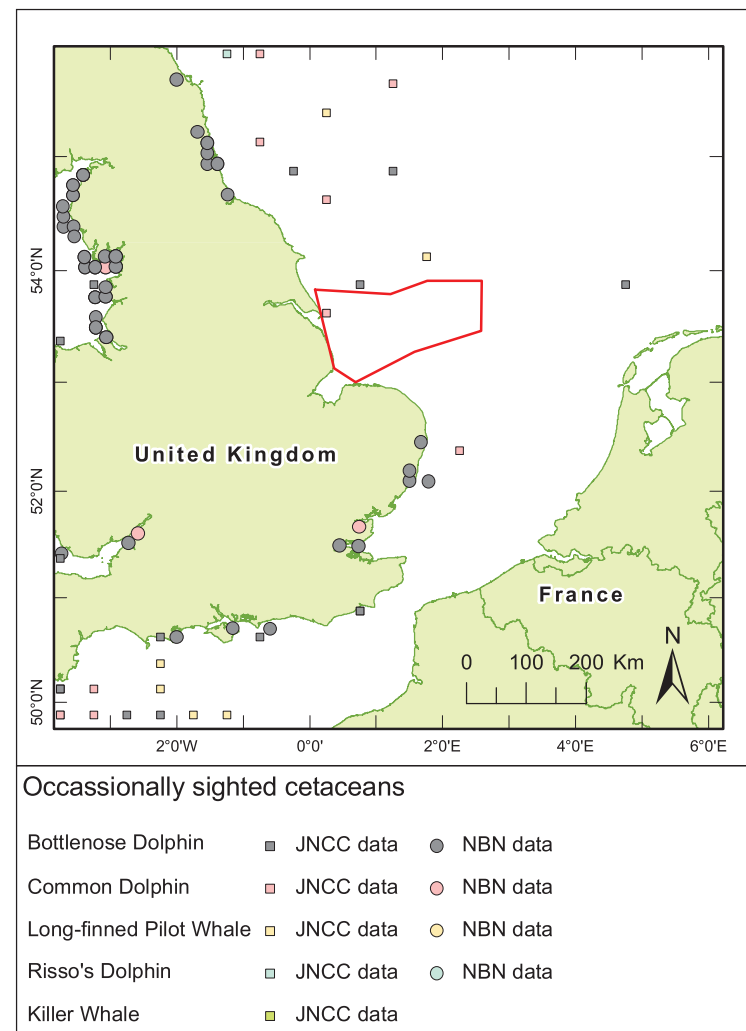


Figure 2.7.9: Recordings of occasionally sighted cetaceans in the east and south of England (JNCC 2003; NBN 2010; Reid *et al.* 2003).

The short-beaked common dolphin, *Delphinus dephis*, (Figure 2.7.11) has also been seen infrequently around the Humber region (Figure 2.7.9). It is however, generally rare in the central and southern North Sea (Evans *et al.* 2003; Reid *et al.* 2003). Seasonal peaks in sightings for eastern England occur in June (Evans *et al.* 2003). The short-beaked common dolphin is a fast, acrobatic and highly active species (Carwardine 2003; Shirihai & Jarrett 2006; Walker & Cresswell 2008).

Orcinus orca, the killer whale, is mainly restricted to the northern North Sea, but has occasionally been sighted in the Humber region

(Evans 1980; Evans 2002; Hammond *et al.* 2002b). Although only an occasional visitor, sightings of killer whales in eastern England peak between July and August (Evans *et al.* 2003). Killer whales are the largest member of the dolphin family; their large robust bodies have distinctive black and white pigmentation and a characteristic white eye patch. The dorsal fin is dark and tall and is generally followed by a white flash on the saddle (Shirihai & Jarrett 2006; Walker & Cresswell 2008).

The Risso's dolphin, *Grampus griseus*, has reportedly been observed on rare occasions in the central and southern North Sea, close to the Humber REC study area (Figure 2.7.9), although the majority of sightings in the North Sea are from the northern areas (Evans 2002; Hammond *et al.* 2002b; Reid *et al.* 2003). Like the killer whale, Risso's dolphin has been reported only as a regular but uncommonly occurring cetacean in the north east Atlantic (Waring, Palka & Evans 2008). Risso's dolphins are easily identified by their heavy scarring and grey-white colour. Scars are usually caused by the teeth of other Risso's dolphins or from prey cephalopods such as octopus and squid (Carwardine 2003; Shirihai & Jarrett 2006; Walker & Cresswell 2008).

2.7.2 The Protected Status of Marine Mammals

The conservation of marine mammals depends on the knowledge of many aspects of their population ecology including population size, structure and distribution. As this information is largely non-existent the best means of protecting many cetacean species is difficult to assess (Reid, Evans & Northridge 2003). Conservation efforts are further complicated because marine mammals migrate across political and geographic borders making their conservation and management a global issue. Numerous national and international conventions and initiatives have been put in place to tackle this problem, those applicable to species occurring in the Humber region are summarised in Table 2.7.1.

The populations of many of the UK's marine mammals have declined over the course of the last 200 years (Reid *et al.* 2003). Numbers have been impacted by direct and indirect fishing pressure, collisions with shipping, pollution and anthropogenic noise (Dietz *et al.* 2001; Dolman, Simmonds & Keith 2003; Hammond 2006; Heriksen *et al.* 2001; Reid *et al.* 2003). In order to ensure that these trends of declining populations are halted the majority of marine mammal



Figure 2.7.10: Long-finned Pilot Whale, *Globicephala melas*
© João Nuno Gonçalves, CIRCÉ - Portugal.



Figure 2.7.11: Common dolphin, *Delphinus dephis*
© João Nuno Gonçalves, CIRCÉ - Portugal.

species now receive legal protection through both European and UK legislation. All of the marine mammal species which are known to regularly occur in the Humber region (Table 2.7.1) are listed in the European Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora 92/43/EEC (the EC Habitats Directive) which was incorporated into UK law as the Conservation (Natural Habitats etc) Regulations in 1994. Cetaceans are listed under Annex IV of

Legislation/Conservation Initiative	Details	Harbour porpoise	White-beaked dolphin	Atlantic white-sided dolphin	Minke whale	Harbour seal	Grey seal
EC Habitats Directive	All cetacean species are protected from capture, killing, disturbance (particularly during periods of breeding) or the destruction of them or their habitat under Annex IV of the Habitats Directive. The UK is also required to designate areas of particular importance to the common dolphin, harbour porpoise, grey and common seals under Annex II. Incidental captures and killing of the common dolphin and harbour porpoise must also be recorded and monitored under Article 12. The Habitats Directive is transposed to UK law by the Conservation (Natural Habitats etc.) Regulations 1994.	*	*	*	*	*	*
Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)	CITES aims to protect certain plants and animals, including cetaceans, by regulating and monitoring their international trade to prevent it reaching unsustainable levels.	*	*	*	*		
The Convention on the Conservation of European Wildlife and Natural Habitats (the Bern Convention)	The principal aims of the Bern Convention are to ensure conservation and protection of all wild plant and animal species and their natural habitats (listed in Appendices I and II of the Convention); to increase cooperation between contracting parties, and to afford special protection to the most vulnerable or threatened species (including migratory species) (listed in Appendix 3). To this end the Convention imposes legal obligations on contracting parties, protecting over 500 wild plant species and more than 1000 wild animal species.	*	*	*	*		
Convention on the Conservation of Migratory Species of Wild Animals (CMS or Bonn Convention)	Migratory species that would significantly benefit from international co-operation of conservation efforts are listed in Appendix II of the Bonn Convention. This encourages member states to conclude global or regional Agreements for the conservation and management of individual species or, more often, of a group of species listed on Appendix II. The Wildlife & Countryside Act and the ASCOBANS agreement are the main mechanisms adopted by the UK in order to implement the recommendations of the Bonn Convention (see below).	*	*	*		*	*
Wildlife and Countryside Act 1981	Act of Parliament which makes it an offence (subject to exceptions) to intentionally kill, injure, take, possess, or trade in any wild animal listed in Schedule 5, and prohibits interference with places used for shelter or protection, or intentionally disturbing animals occupying such places. The common dolphin, bottlenose dolphin and harbour porpoise are also listed under Schedule 6 which prevents them from being killed by certain methods.	*	*	*	*		
Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)	Regional agreement covering all species of the toothed whales (<i>Odontoceti</i>), with the exception of the sperm whale (<i>Physeter macrocephalus</i>). A conservation and management plan forms part of the agreement and this obliges parties to engage in habitat conservation and management, surveys and research, pollution mitigation and public information.	*	*	*			
Section 74 Countryside Rights of Way (CROW) Act 2000	The CROW Act amends the law relating to nature conservation and protection of wildlife. Section 74 of the Act requires the preparation and maintenance of lists of priority species and habitats. The CROW Act also strengthens the legal protection for threatened species with regard to killing, injuring, disturbing or destroying places used for shelter and protection.	*	*	*	*		
Conservation of Seals Act 1970	Provides for a closed season during which it is an offence to take or kill any seal except under licence in particular circumstances. The closed season for grey seals is 1 September to 31 December inclusive and for common seals, 1 June to 31 August inclusive, coinciding with their respective pupping seasons. The act provides an exception which makes it lawful to kill a seal to prevent it from causing damage to fishing nets or tackle, or to any fish in the net, providing the seal is in the vicinity of the net or tackle at the time.					*	*
UK Biodiversity Action Plan (BAP)	The UK List of Priority Species and Habitats contains 1150 species and 65 habitats that have been listed as priorities for conservation action under the UK Biodiversity Action Plan (UK BAP).	*	*	*	*	*	

Table 2.7.1: The national and international conventions and initiatives that apply to the marine mammals of the Humber REC study area.

the Directive which means they are strictly protected. All forms of deliberate capture or killing are prohibited, as is the disturbance or destruction of the animals themselves or the habitats which they use for breeding or resting. Similarly, it is illegal under the UK Wildlife and Countryside Act (1981) to intentionally kill, injure or harass any cetacean species in UK waters (Reid *et al.* 2003).

Conservation efforts are likely to be greatly enhanced as more data become available and our understanding of the ecology of marine mammals improves. In recent years there has been a trend towards coordinated sea surveys which yield valuable information on the distribution and population dynamics of marine mammals. Examples of such surveys include the small cetaceans in the European Atlantic and North Sea (SCANS), a survey dedicated to all small cetaceans in the North Sea and adjacent waters (Hammond *et al.* 2002a; Hammond 2006). Observational data from a number of sources has also been collated and is published in the Atlas of Cetacean distribution in north-west European waters (Reid *et al.* 2003).

The data from this publication has been used to map distributions of cetaceans in the Humber region, shown in yellow in Figures 2.7.2, 2.7.4, 2.7.6, 2.7.8, 2.7.9. Three sources contributed to this collated data; the Small Cetacean Research Unit (SCANS 1994 and SCANS-II 2005), Sea Watch and European Seabirds at Sea (ESAS). Although this data is collected from several sources it is believed to be outdated and may not accurately reflect cetacean distribution and relative abundance in UK waters. There are also inconsistencies within marine mammal literature and the publicly available data. However, it is the best data covering UK waters and is represented in yellow in the figures referred to above. Data from the National Biodiversity Network Gateway (2010) is also shown in grey.

JNCC are currently leading a collaborative project, the Joint Cetacean Protocol, which aims to assess the cetacean reporting requirements of various European directives and identify all relevant NW European cetacean data available for reporting on cetacean conservation status. The project will investigate what power these data have to assess trends in abundance and range and how to improve that power and will determine what standards data must attain to enable high quality reporting. It also aims to facilitate the sharing of standardized cetacean datasets via

the world wide web and to generate tools for the production of cetacean distribution and abundance summary data.

2.7.3 Pinnipeds of the Humber Region

Harbour Seal — *Phoca Vitulina*

The harbour seal, *Phoca vitulina*, (Figures 2.7.12 and 2.7.13) is the most widely distributed pinniped in the North Sea (Hammond *et al.* 2002b). *P. vitulina* occurs in all coastal waters around the North Sea with an estimated minimum population of 38 000, which is over half of the total estimated northeast Atlantic population (Hammond *et al.* 2002b).

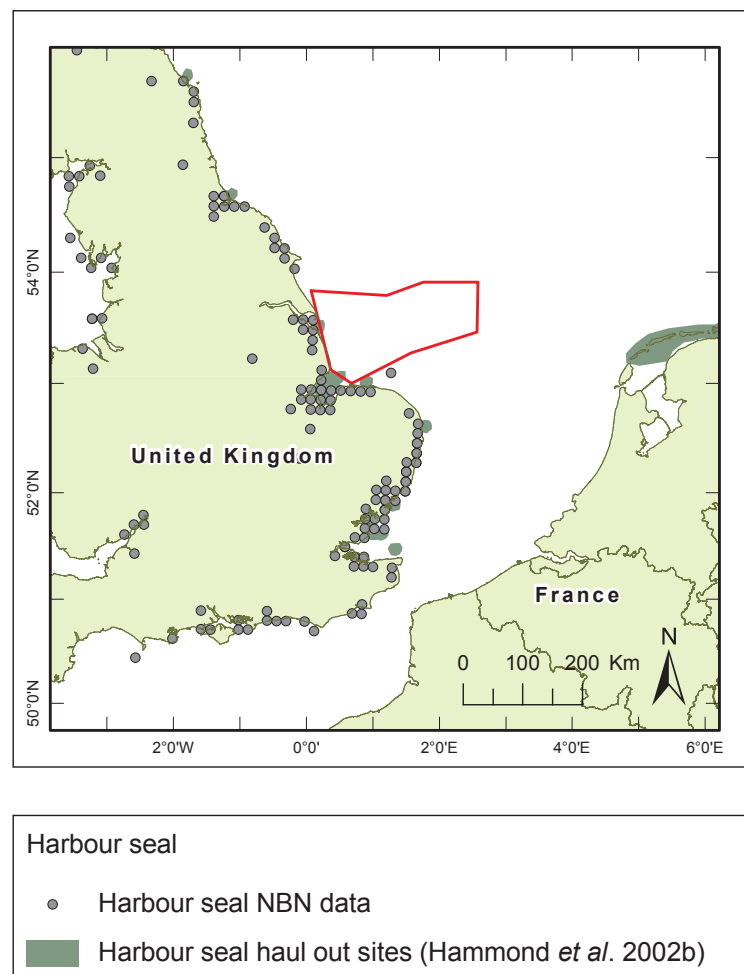


Figure 2.7.12: Recorded sightings, distribution and haul out sites of harbour seals, *Phoca vitulina*, in the Humber REC study area (Hammond *et al.* 2002b; NBN 2010; Reijnders, Verriopoulos & Brasseur 1997).

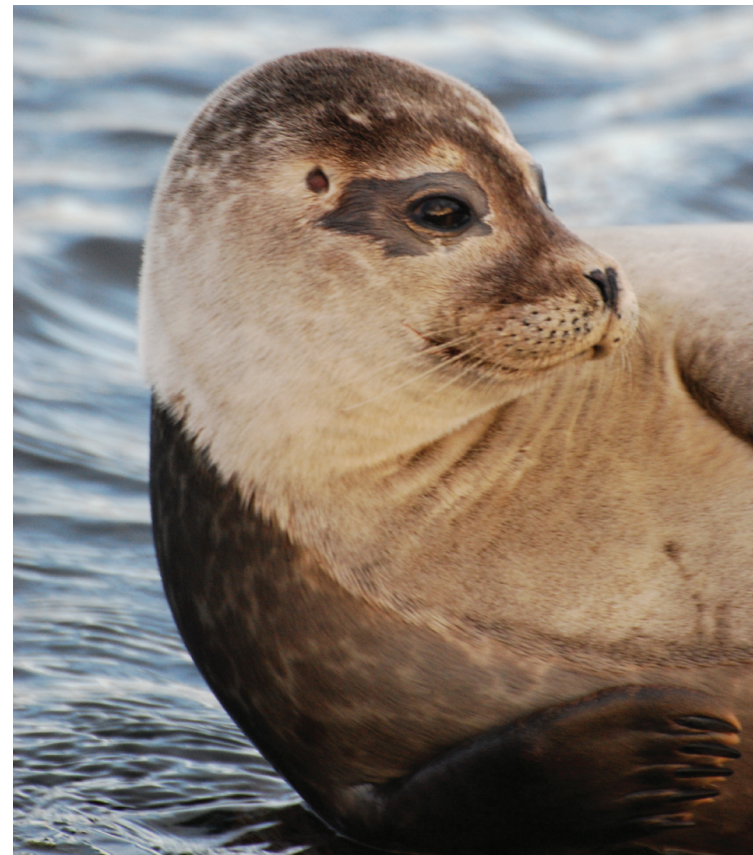


Figure 2.7.13: Harbour Seal, *Phoca vitulina* © Marine Wildlife Department of Gardline Environmental.

The North Sea provides major haul out sites on tidally exposed rock, sandbanks and mud where animals come ashore for pupping and moulting (Das *et al.* 2003; Hammond *et al.* 2002b). Donna Nook, on the south bank of the River Humber, and The Wash, an area very close to the Humber REC study area, are both areas in the North Sea which host major population of the harbour seal (Lonergan *et al.* 2007; Reijnders & Lankester 1990). The colonies at Donna Nook, The Wash and Blakeney Point (Norfolk) are thought to account for over 90% of the whole English population of *P. vitulina* (Lonergan *et al.* 2007). Aerial surveys estimate that on the English east coast 3 700 individuals haul out onto land for the moult and pupping seasons (Hammond *et al.* 2002b). Pupping occurs from June to July and the moult around August to September (Hammond *et al.* 2002b). Figure 2.7.12 illustrates known haul out sites for the harbour seal around the English coast,

it shows that there are several haul out sites in and around the Humber REC study area.

The need to return to land means that harbour seals are normally restricted to distances less than 60 km from shore, however recent studies in Scotland, Denmark and the Netherlands have shown that they are widely distributed across the North Sea (Hammond *et al.* 2002b). Hammond *et al.* (2002b) suggest it is highly likely that harbour seals inhabiting the east coast are also likely to frequent areas further offshore (Hammond *et al.* 2002b). *Phoca vitulina* is widely distributed over at least half of the Humber REC study area (Figure 2.7.12).

Grey Seal — *Halichoerus Grypus*

Although the harbour seal is the most widespread, the grey seal, *Halichoerus Grypus* (Figures 2.7.14 and 2.7.15) has the highest abundance in the North Sea with an estimated population of 300 000 individuals, of which 14 100 are estimated to reside on the UK coast (Hammond *et al.* 2002b). Hauling and breeding sites for *H. Grypus* are mostly found around the northern UK coast. However, more recent sightings and strandings in the southern region of the North Sea suggest that this species is extending southwards (Das *et al.* 2003). Grey seal movements from haul out sites are localised over gravel and sand beds which are linked to sand eel habitat. Trips to and from haul out sites are generally short in duration, typically 2–3 days (Hammond *et al.* 2002b).

The southernmost concentration of grey seals on the east coast can be found on the south bank of the River Humber at Donna Nook (Lincolnshire) (Figure 2.7.14). The Humber is one of three major grey seal colonies in Britain where breeding occurs (Abt *et al.* 2002). An estimated 400 individuals frequent this area every year and approximately 120 pups are born each December (English Nature 2003; Prime & Hammond 1990). Prime and Hammond (1990) estimate a 135 km feeding radius from Donna Nook, encompassing Flamborough Head, parts of Dogger Bank and most of the Norfolk Banks (Figure 2.7.14) indicating the Humber as a significant feeding and breeding area for grey seals (Abt *et al.* 2002; Prime & Hammond 1990).

Both harbour and grey seals are important predators in the North Sea, commonly consuming prey such as sand eels, gadoids

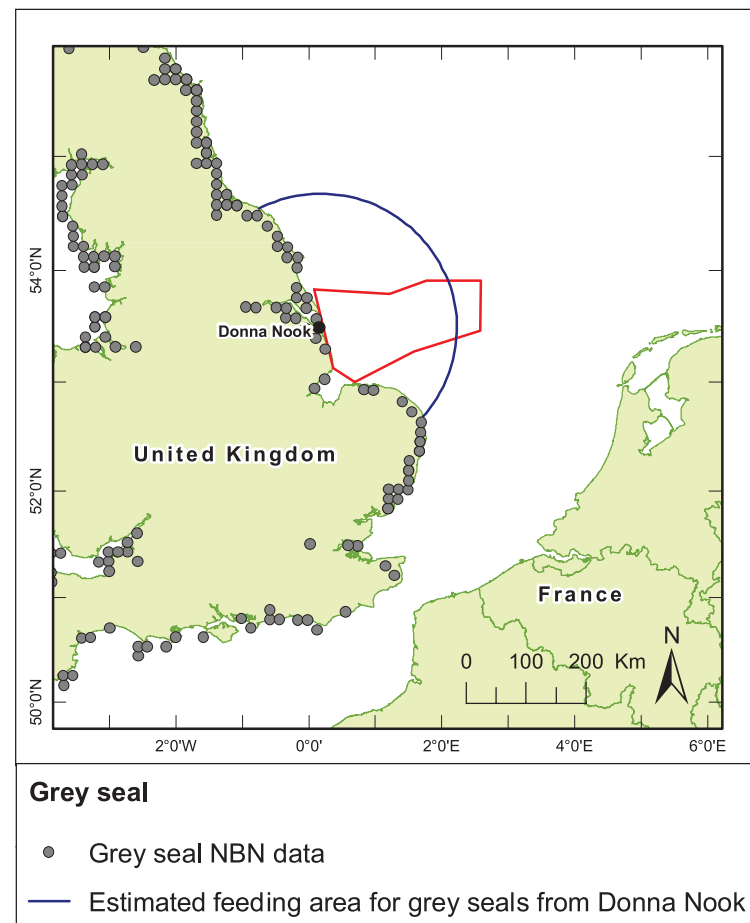


Figure 2.7.14: Recorded sightings and estimated feeding radius of grey seal, *Halichoerus grypus*, in the Humber REC study area (NBN 2010; Prime & Hammond 1990).



Figure 2.7.15: Grey Seal, *Halichoerus grypus* © Marine Wildlife Department of Gardline Environmental.

and flatfish (harbour seals also predate other clupeoid fish and cephalopod species) (Hall *et al.* 1998; Hammond *et al.* 2002b; Pierce & Santos 2003; Prime & Hammond 1990). Along with the white-beaked dolphin and cod they occupy the highest trophic position in the North Sea, with very few natural predators of their own (Das *et al.* 2003). In the North Sea the grey seal has been estimated to consume approximately 130 000 tonnes of prey a year, and the harbour seals' estimated annual prey consumption is 65 000 to 95 000 tonnes (Hammond *et al.* 2002b). Grey seals are often considered a nuisance as their fish consumption competes with commercial fisheries (Matthiopoulos *et al.* 2008; Reijnders & Lankester 1990).

Multispecies Associations

Cetaceans and seabirds forge multi-species feeding associations in the North Sea. Marine mammals act as 'beaters', forcing fish balls to the surface providing seabirds with access to prey such as sandeels and clupeoid fish that would otherwise be too deep to catch (Camphuysen & Webb 1999; Frederiksen *et al.* 2006). Camphuysen and Webb (1999) observed a 'typical association' of Atlantic white-beaked dolphins and harbour porpoises displaying this beating behaviour for Northern gannets and black-legged kittiwakes. Minke whales are associated with auks, kittiwakes, large gulls, Manx shearwaters and shags (Anderwald & Evans 2008). Cetaceans can also provide scraps of prey and faeces for scavenging birds (Camphuysen & Webb 1999). These multispecies feeding associations are important in assisting the 'visual food-finding' abilities of seabirds (Camphuysen & Webb 1999).

The Humber REC study area is an important area for several marine mammal species providing habitat, feeding grounds and breeding grounds. It is a particularly important area for the harbour porpoise, *Phocoena phocoena*, harbour seal, *Phoca vitulina*, and the grey seal, *Halichoerus grypus*. There is a demand for more research into marine mammal distribution and behaviour across the UK, including the Humber region. More accurate distribution data and behavioural research could give more of an insight into how this particular area is being utilised by marine mammal species and the role they play within the ecosystem.

2.8 Ornithology

2.8.1 The Humber Region

The Humber region and adjacent coastline have internationally important sites for bird species, particularly the Humber Estuary and the chalk cliffs at Flamborough Head and Bempton Cliffs (Figure 2.8.1). There are several important breeding and feeding areas and the region also falls within internationally important migratory routes for many species (Allen *et al.* 2003). The varied geology of the coastline gives rise to chalk cliff, marsh land, rocky and sandy beach habitats which are used as nesting areas by a wide array of birds (Allen *et al.* 2003).

During the period of 1999–2004 the Humber region supported a mean annual peak maxima of 177 554 birds including species of gulls, divers and terns (Bank *et al.* 2005). However, due to the migratory nature of many bird species and the seasonality of visitor numbers the actual number of species utilising the area is thought to be three times greater than the peak maxima (Allen *et al.* 2003). The area is increasingly important for waterfowl and between 1980 and 2000 the numbers of these species using the area increased from 73 141 to 170 927. Increases in numbers were most notable for the common guillemot (*Uria aalge*) and the kittiwake (*Rissa tridactyla*), which are amongst the most common seabirds in the area.

The Humber Estuary is one of the six most important wetland sites in the UK. The estuary is positioned along the East Atlantic Flyway, a bird migratory route which connects arctic and sub-arctic nest sites to over-wintering sites in southern Europe and Africa (Allen *et al.* 2003). The Humber Estuary provides a useful stopping and refuelling station for many birds during these migrations. The mudflat and saltmarsh habitats of the Humber Estuary are particularly productive and provide important foraging and nesting resources for seabirds (Allen *et al.* 2003; RSPB 2009). Because of the large numbers of birds that use the area, the Humber Estuary is a designated Ramsar site and also includes a recognised SPA (Special Protection Area) implemented under the EU Birds Directive (79/409/EEC) (Burdon & Cutts 2008; JNCC 2009).

The chalk cliffs at Flamborough Head and Bempton Cliffs are Special Protected Areas (SPA) and area recognised as particularly important bird areas, Figure 2.8.1. The cliffs at both locations can reach 120 m

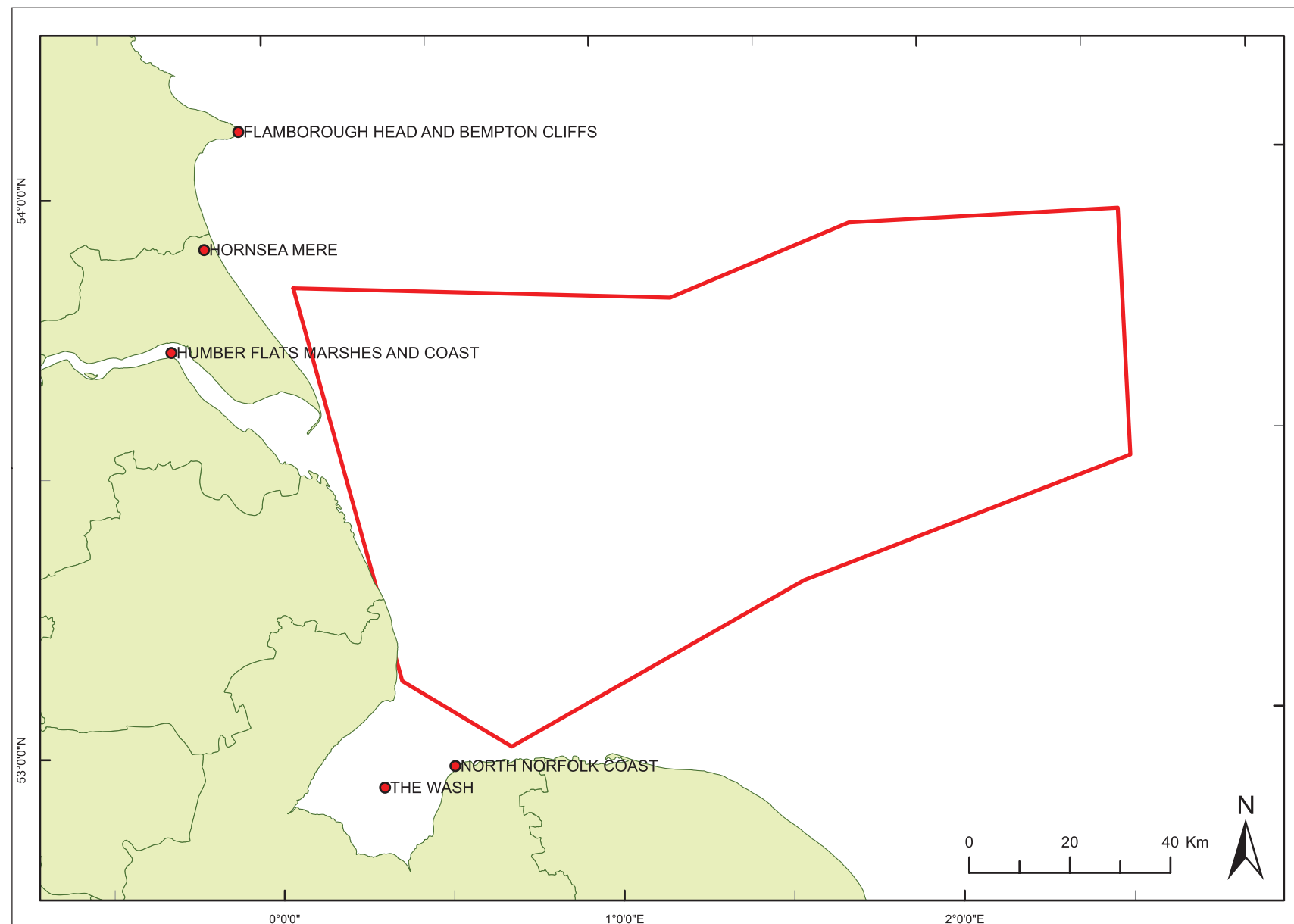


Figure 2.8.1: The Humber REC study area and recognized important bird areas found along the adjacent coastline.

in height providing safe refuges for nesting and breeding birds. Both sites regularly support over 46 100 pairs of breeding seabirds and 76 000 pairs of breeding waterfowl (RSPB 2009). Over 300 000 individual breeding seabirds have been estimated to use these sites during the course of a year (Stroud *et al.* 2001). Particularly important to the area is the gannet (*Morus bassanus*) population, which is the only UK site, outside Scotland and Wales, to support breeding

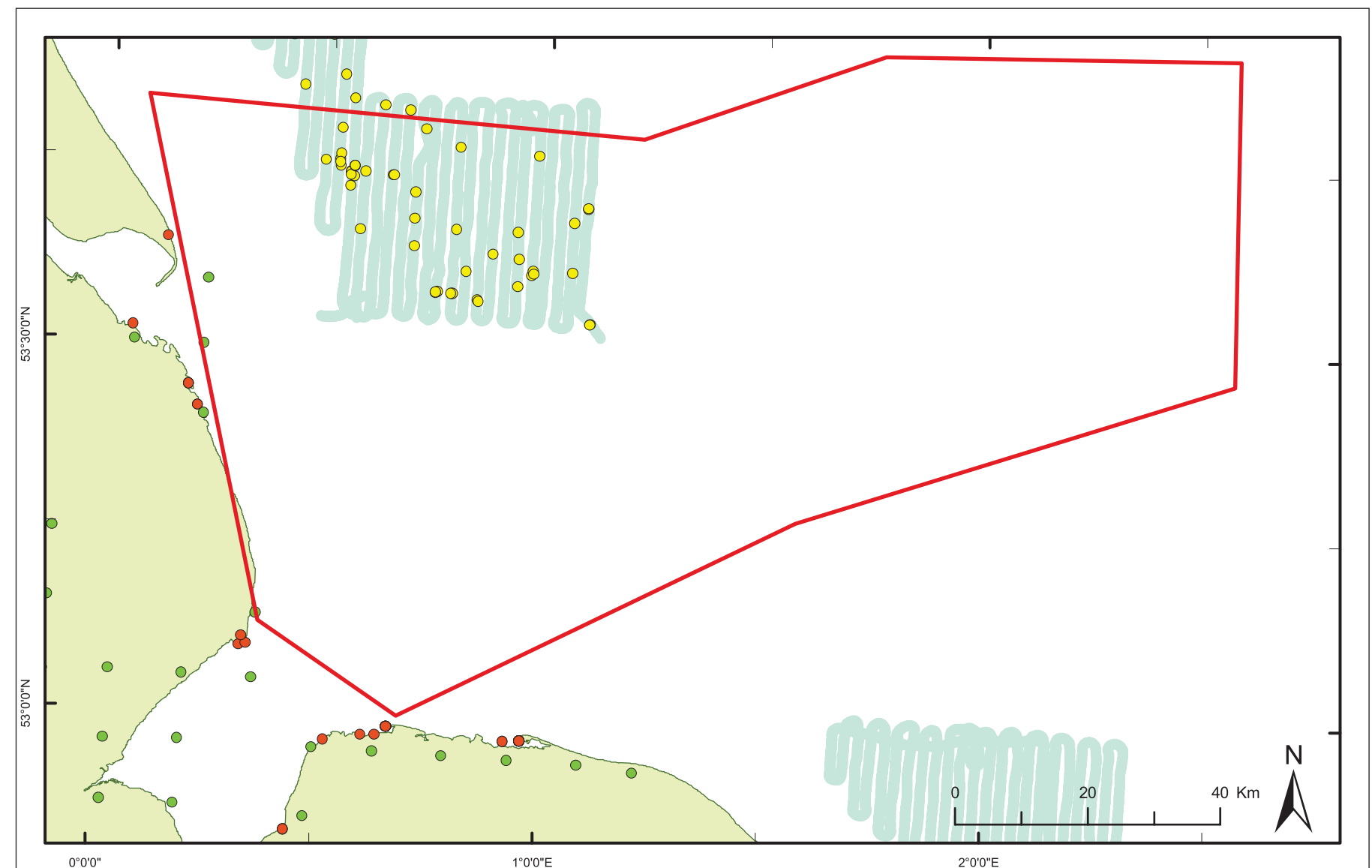
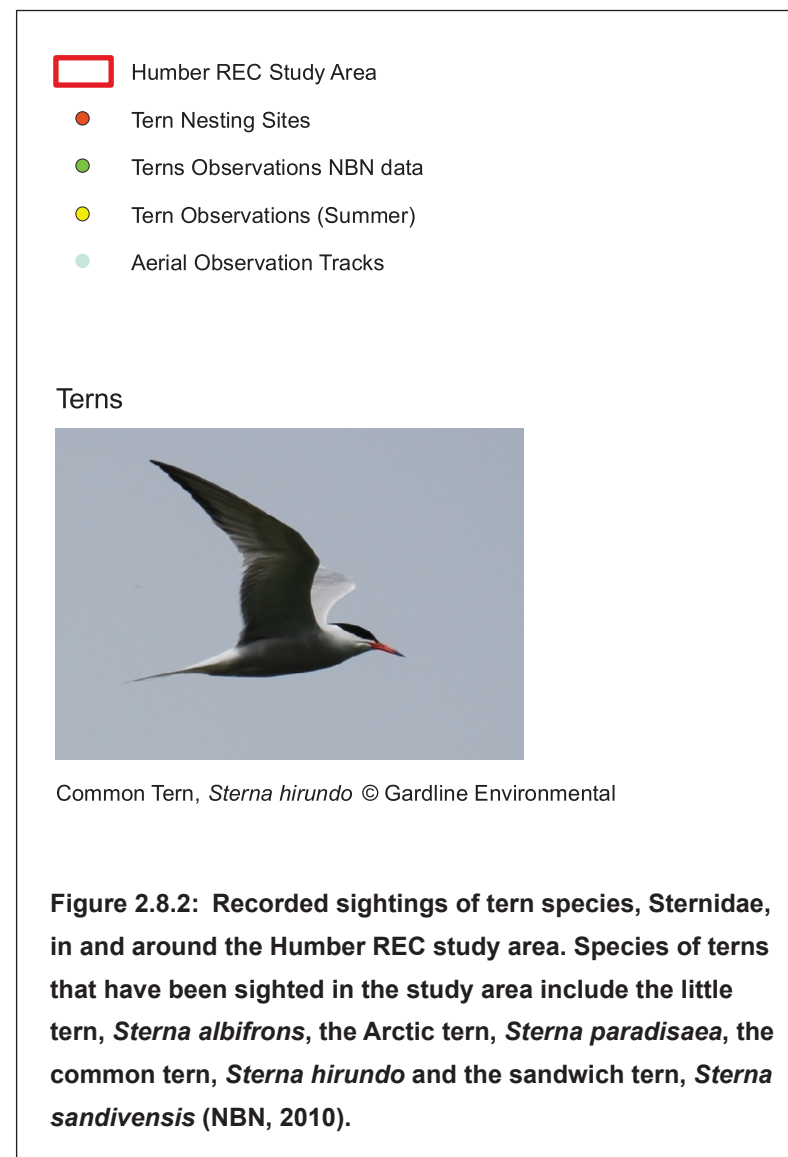
individuals. The number of gannets utilising the area is thought to be around 2 500 individuals (Stroud *et al.* 2001).

Several important commercial fish species, such as the lesser sandeel (*Ammodytes marinus*), sprat (*Sprattus sprattus*) and capelin (*Mallotus villosus*) are known to be target prey for seabirds in the Humber region (Furness & Tasker 2000; Bull *et al.* 2004). Fisheries in the area therefore exert an influence on the distribution

and behaviour of seabird feeding and population dynamics, through indirect and direct trophic interactions and mortality from fishing gear (Garthe, Camphuysen & Furness 1996; Kirby, Holmes & Sellers 1996; Furness & Tasker 2000; Votier, Heubeck & Furness 2008; Frederiksen *et al.* 2006).

Concerted and co-ordinated seabird monitoring in the UK has occurred since 1986, when the Seabird Monitoring Programme (SMP) started to collect annual data (Sims *et al.* 2006; Mavor *et al.* 2008). Other surveys that have helped our understanding of bird trends in the UK are Operation Seafarer (1969–1970), Seabirds 2000 (1998–2002) and Seabird Colony Register (1985–1988) (Gibbons, Evans & Gregory 2009). Avian data acquisition is mainly concentrated around coastal and inland areas, although boat data is available through databases such as ESAS (European Seabirds at Sea). ESAS was set up to standardise bird surveying techniques and data formatting for studies conducted around the North Sea (Camphuysen & Garthe 2004). Data has also been retrieved from the National Biodiversity Network (NBN) gateway, which collates and presents biodiversity data for the UK. Surveying techniques include boat and aerial surveys as well as land-based observations (Gibbons *et al.* 2009). The data points, representing bird observation data, presented in this report have been divided into summer and winter observations and nest sites. Sightings by aerial surveys have also been highlighted.

These observations help to build a picture of population trends and are used to define the conservation status of birds in the UK and Europe. The Birds of Conservation Concern categorises birds into red, amber and green status according to quantitative criteria and this information is used by organisations such as the RSPB (Gibbons *et al.* 2009). Other waterfowl birds that have not been mapped or dealt with below, but are listed under Annex 1 of the EU Birds Directive and are found in the Humber area at some time during the year include; the marsh harrier, avocet, wintering bittern, hen harrier, golden plover and bar-tailed godwit (Allen *et al.* 2003). There are also a number of migratory birds that are not listed under Annex 1 that qualifies the site as an SPA under Article 4.1 of the EU Birds Directive (Burdon & Cutts 2008; JNCC 2009). These birds include the ringed plover, redshank, shelduck, grey plover, lapwing, dunlin and knot (Allen *et al.* 2003).



2.8.2 Bird Species of Interest across the Humber Region

Terns — Sternidae

There are several tern species that are common to the Humber REC study area (Figure 2.8.2). The terns are a group of small to medium sized migratory birds that are white, silver-grey and exhibit a black cap during the summer months. Terns visit the UK in the summer months when they are observed at coastal nest sites and there are also inshore and offshore aerial sightings.

The little tern, *Sterna albifrons*, has established breeding sites along the outer Humber Estuary (Allen *et al.* 2003). The Humber Estuary regularly supports 2.1% of the total population of little terns

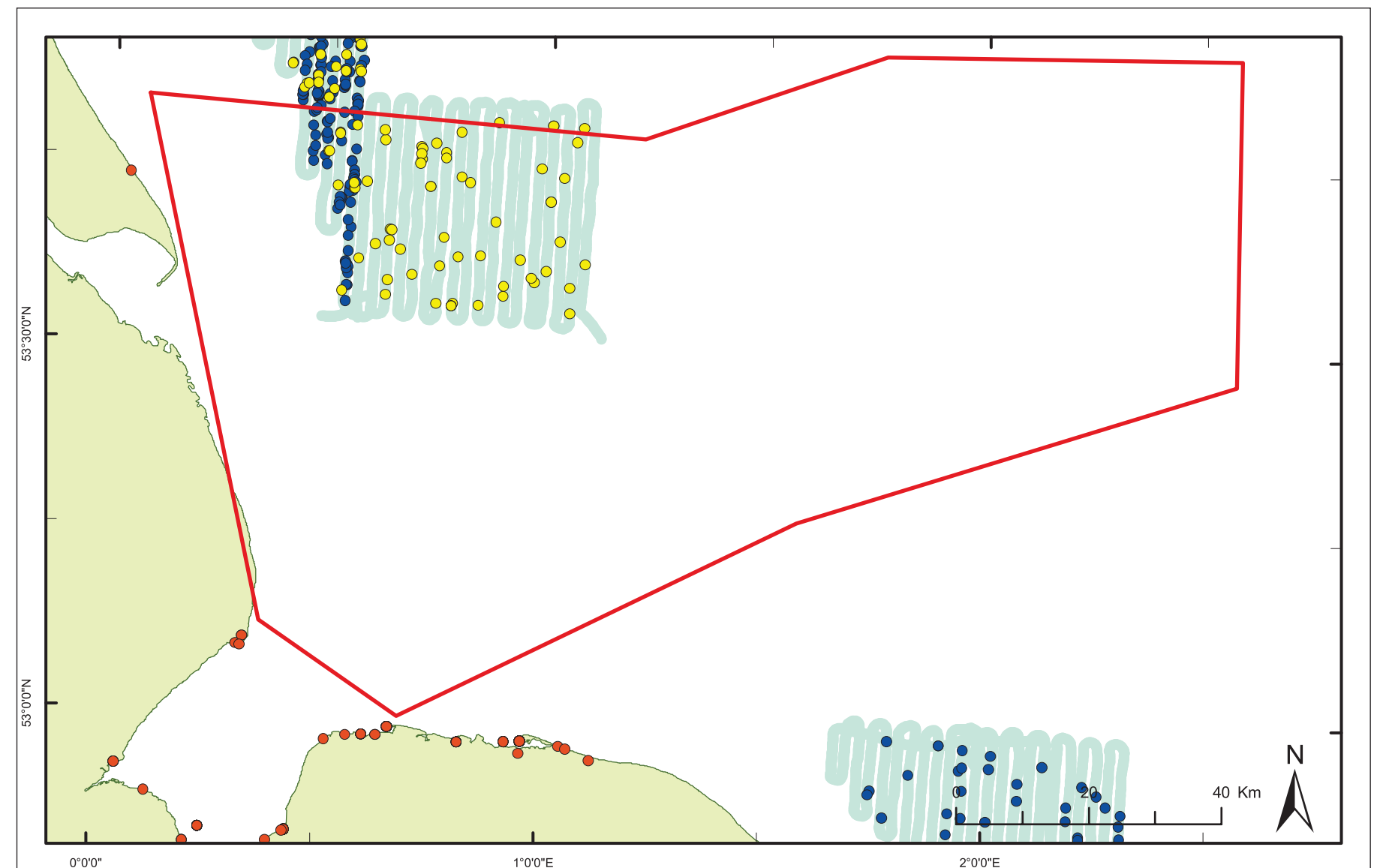
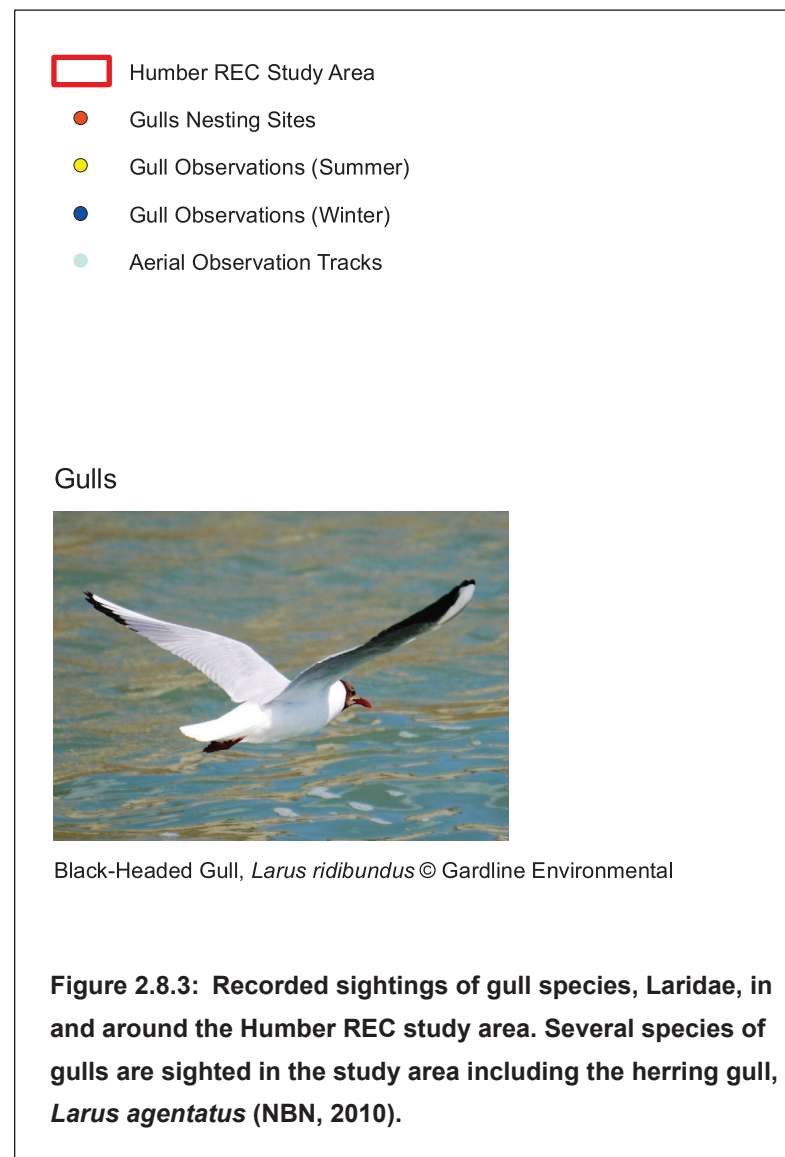
in Great Britain during the breeding season (figures from 1998–2002), and their presence in the regions has helped to establish the area as a Ramsar site and SPA (JNCC 2009; RSBP 2009). The little tern is declining in numbers throughout Europe and has been listed as an Annex 1 species under the EU Birds Directive and is also included in the amber category of the Birds of Conservation Concern (Gibbons *et al.* 2009).

The Arctic tern, *Sterna paradisaea*, also visit the Humber region as they undertake their mammoth migrations, of around 20 000 km, from breeding grounds in the Arctic and temperate northern hemisphere to their wintering sites in the Antarctic (Gudmundsson, Alerstam & Larsson 1992; RSBP 2009). Arctic terns visits the UK in

May–June and the coastal and inland areas of the Humber provide important resources during their migration route (RSBP 2009).

The Arctic tern is listed as amber under the Birds of Conservation Concern listing (Gibbons *et al.* 2009). Moderate declines in the breeding population of Arctic terns have been attributed to declines in numbers of their prey, the lesser sandeel, *Ammodytes marinus* (Furness & Tasker 2000).

Two other tern species in the amber category of the Birds of Conservation Concern listing, the common tern (*Sterna hirundo*) and the sandwich tern (*Sterna sandivensis*) also frequent the Humber region during the summer months (Gibbons *et al.* 2009; RSBP 2009).



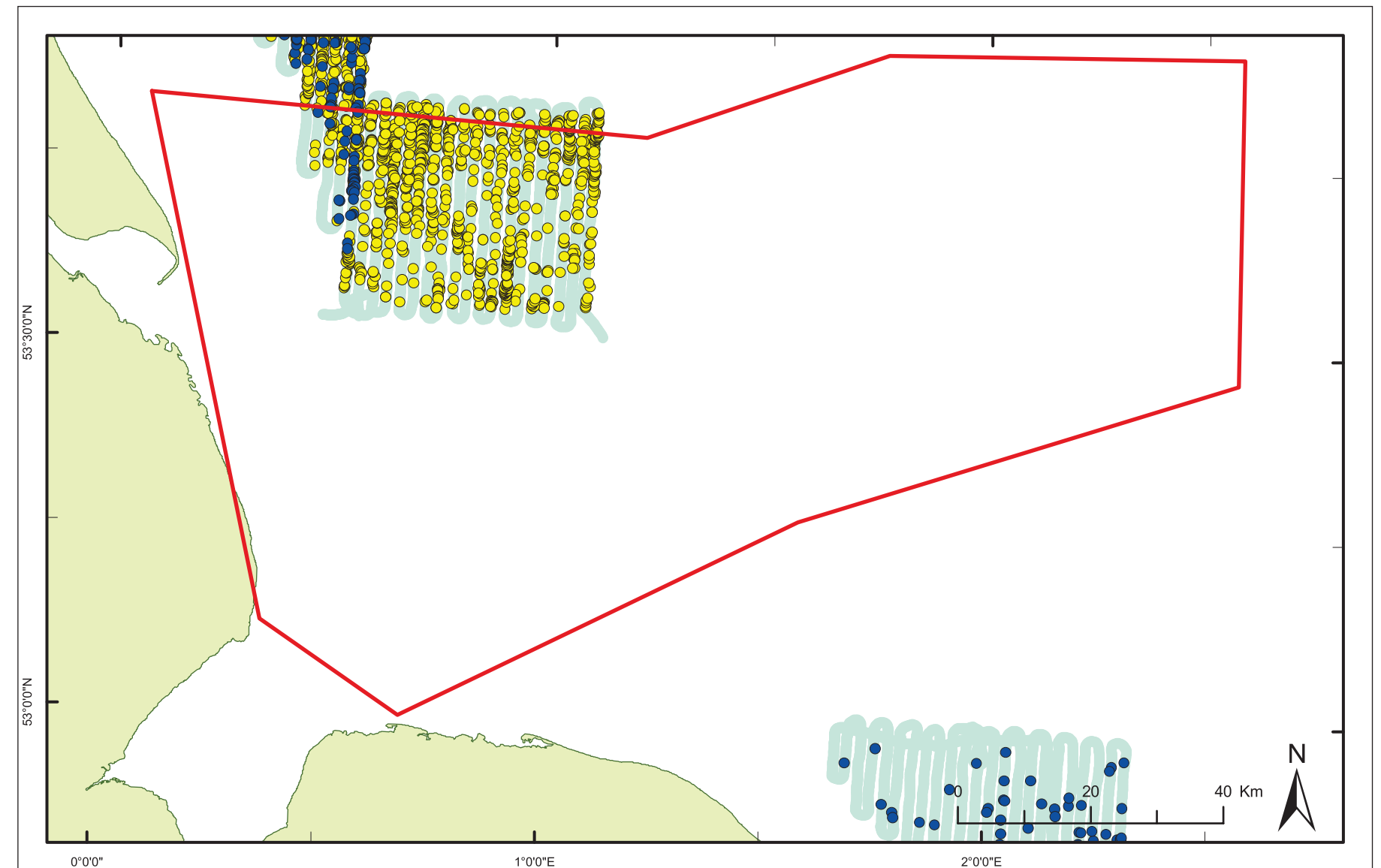
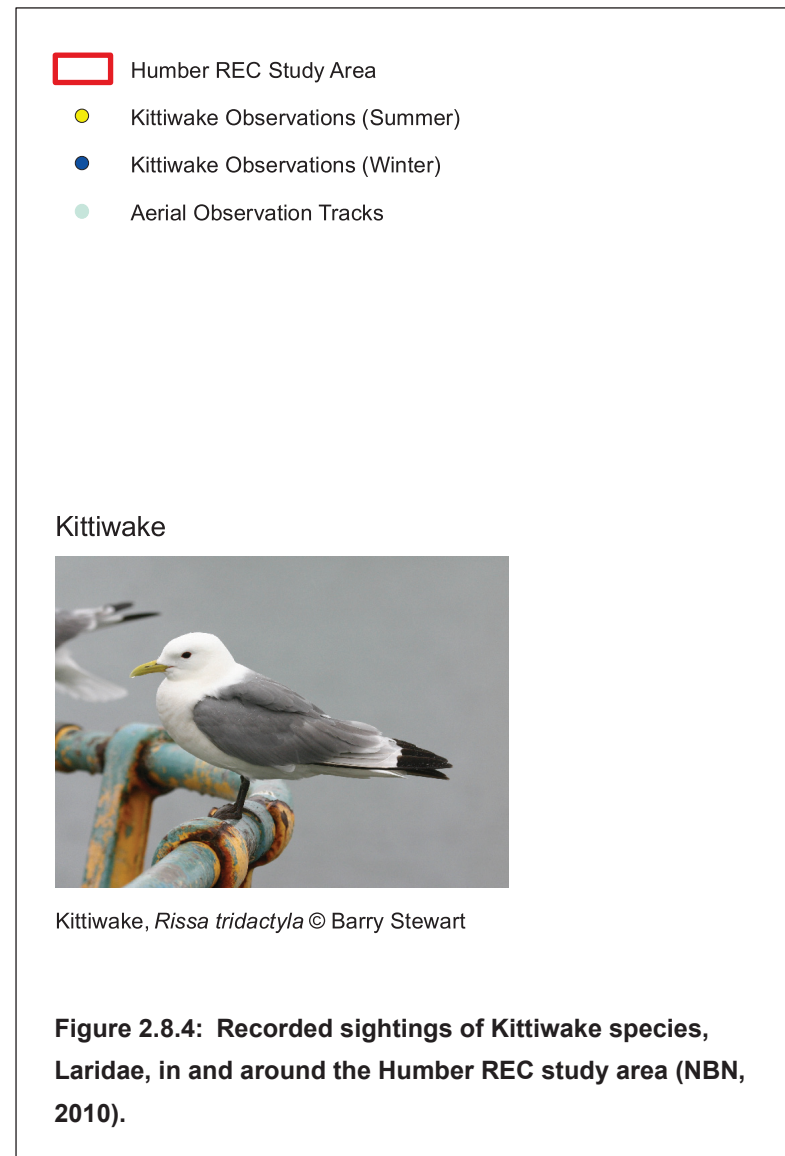
Gulls — Laridae

The gulls, informally known as 'seagulls' are easily identifiable by their white and grey plumage, often accentuated with black markings (RSBP 2009) (Figure 2.8.3). Gulls are generalist predators that feed on shoaling fish, fishery discards and smaller birds, especially when other prey sources are scarce (Votier *et al.* 2008). Gulls will also readily scavenge from inshore bins and rubbish tips (RSBP 2009). Of the many European species ten are regularly found in the UK and these all frequent the Humber region with nest and aerial observations recorded in both summer and winter months (Figure 2.8.3). Datasets retrieved from the

NBN gateway have not been added due to the high number of observations, which would obscure data from other sources.

The herring gull, *Larus argentatus*, is a large bird that is distinguished from other gulls by pink legs and a hooked beak that sports a red dot. This species is found all year round in the Humber region, both on the coast and inland. Severe declines in the breeding population, of over 50 percent in the last 25 years, has meant the herring gull has been placed under the red status of Birds of Conservation Concern (Gibbons *et al.* 2009). This population decline is thought to be connected to the reduction

in fishery discards, which has negatively impacted scavenging seabirds (Montevecchi & Myers 1997). The UK population of the herring gull is of international importance, accounting for at least 20 percent of Europe's non-breeding population (Gibbons *et al.* 2009).



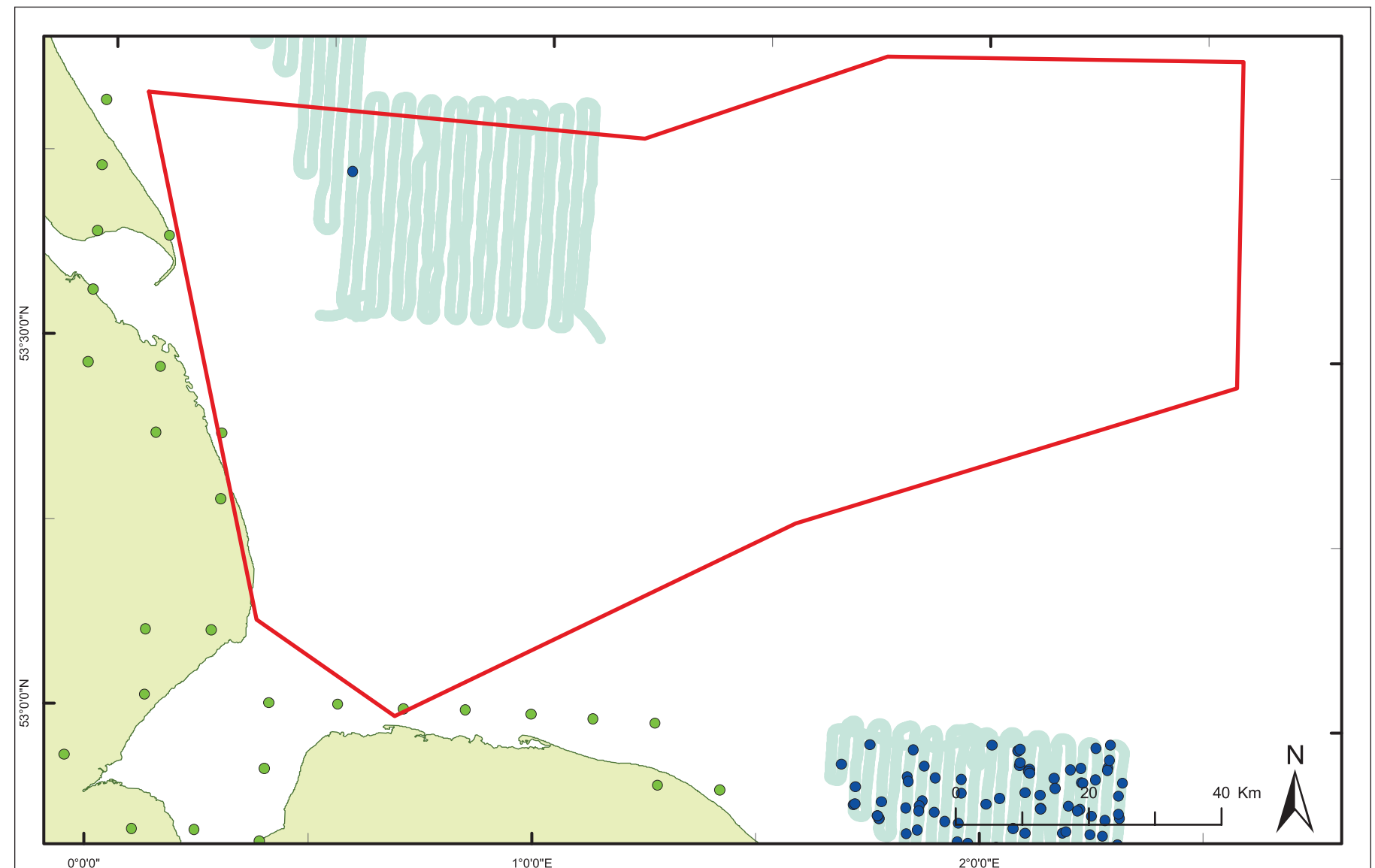
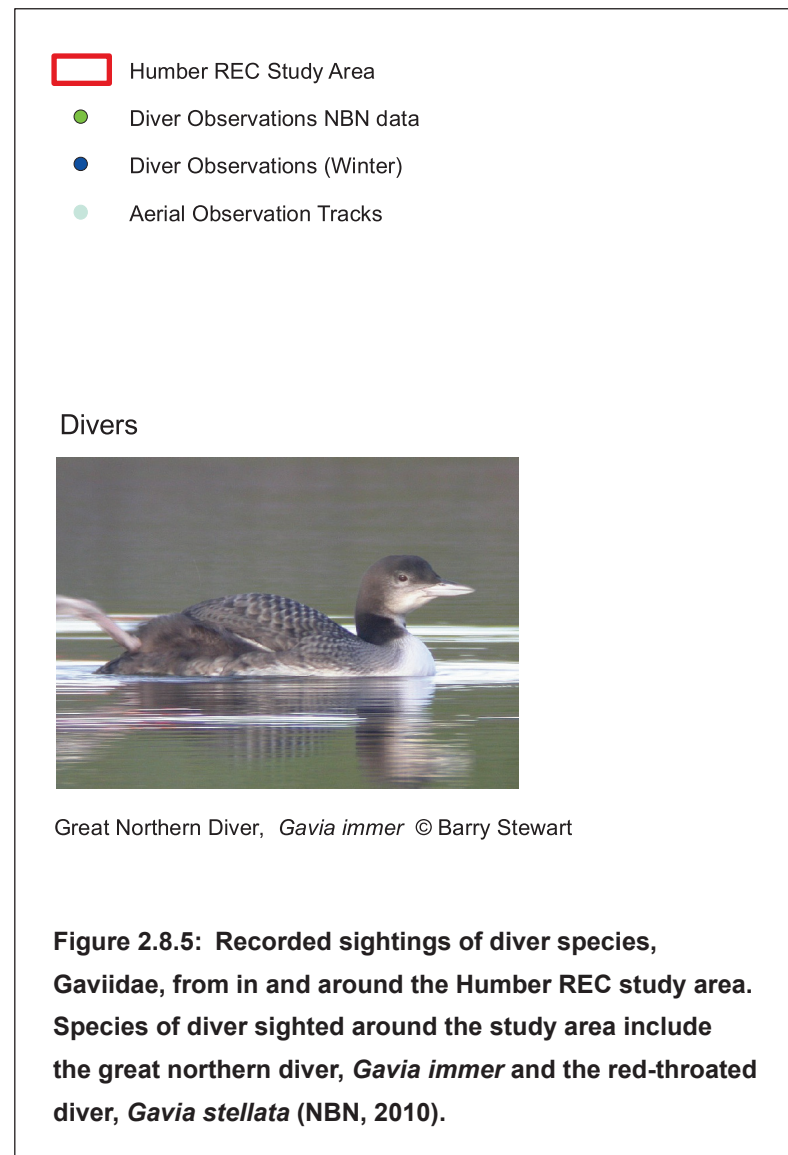
Kittiwakes — Laridae

The kittiwake, *Rissa tridactyla*, is a medium sized gull with a white head, grey wings and black tail feathers. It can be observed surface feeding and diving for sandeels (*Ammodytes marinus*), herring (*Clupea harengus*), sprats (*Sprattus sprattus*) and capelin (*Mallotus villosus*) (Bull *et al.* 2004).

Kittiwakes have breeding sites to the north of the Humber Estuary (Bull *et al.* 2004) and there are aerial observations in the region in

summer and winter (Figure 2.8.4). The kittiwake population in the North Sea as a whole has declined by 50 percent in the last two decades and has been listed under the amber category of Birds of Conservation Concern (Votier *et al.* 2008; Gibbons *et al.* 2009; Mitchell 2009). The population decline and reduction in breeding success has been attributed to reductions in their main prey, the lesser sandeel, and a switch to nutritionally poor substitutes such as the snake pipefish (Harris *et al.* 2008). An increase in predation of kittiwakes by the great skua has also impacted the

population (Votier *et al.* 2008). The kittiwake nest sites in the Humber region are important as over 50 percent of the breeding population are confined to ten or fewer UK sites (Gibbons *et al.* 2009). There are no nest sites shown on Figure 2.8.4 despite it being known that the Humber region is an important breeding area for this species. This may be due to the fact that they nest on cliff faces and inaccessible areas, so no sites were recorded in the JNCC data set that was used to map nest sites.



Divers — Gaviidae

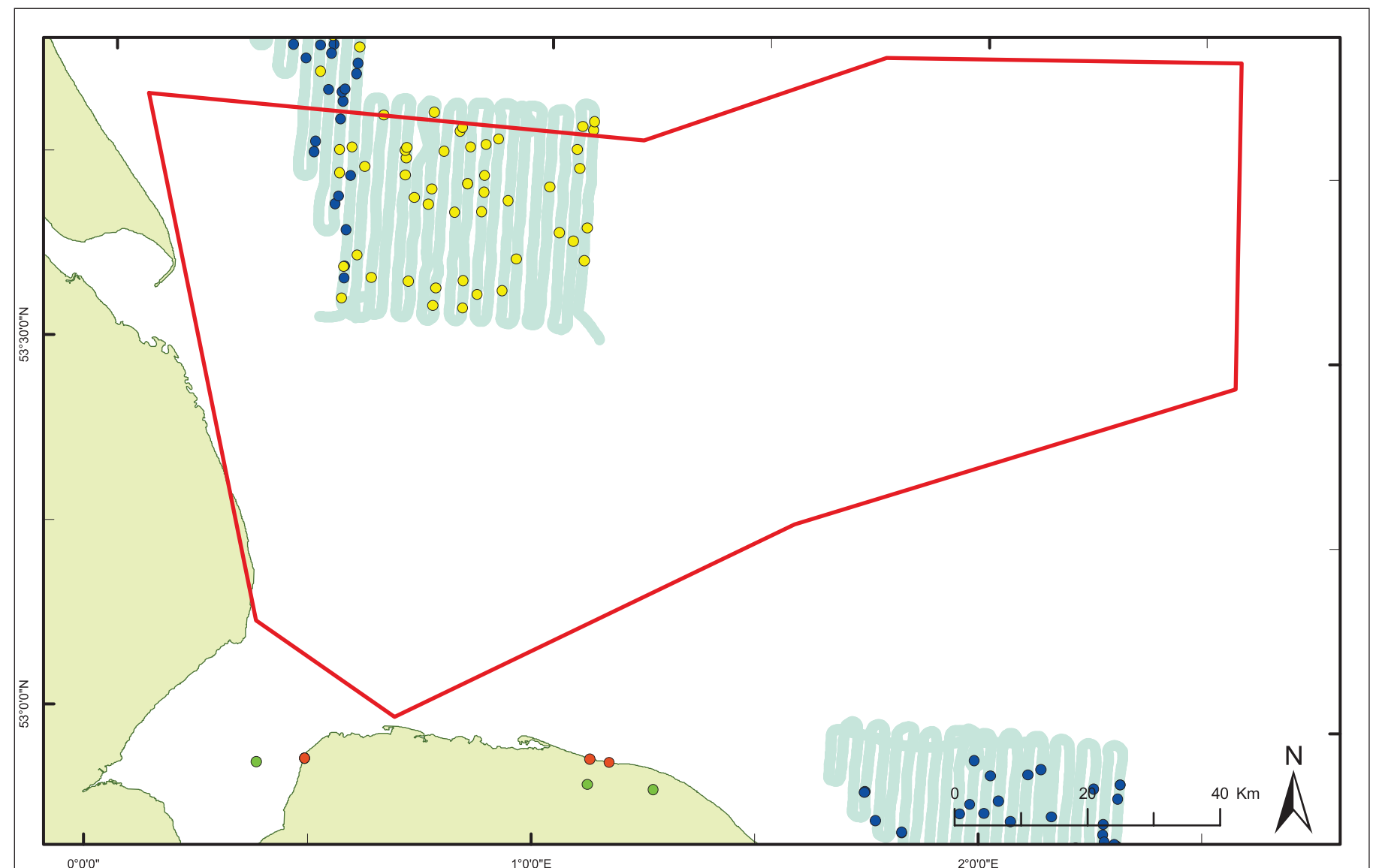
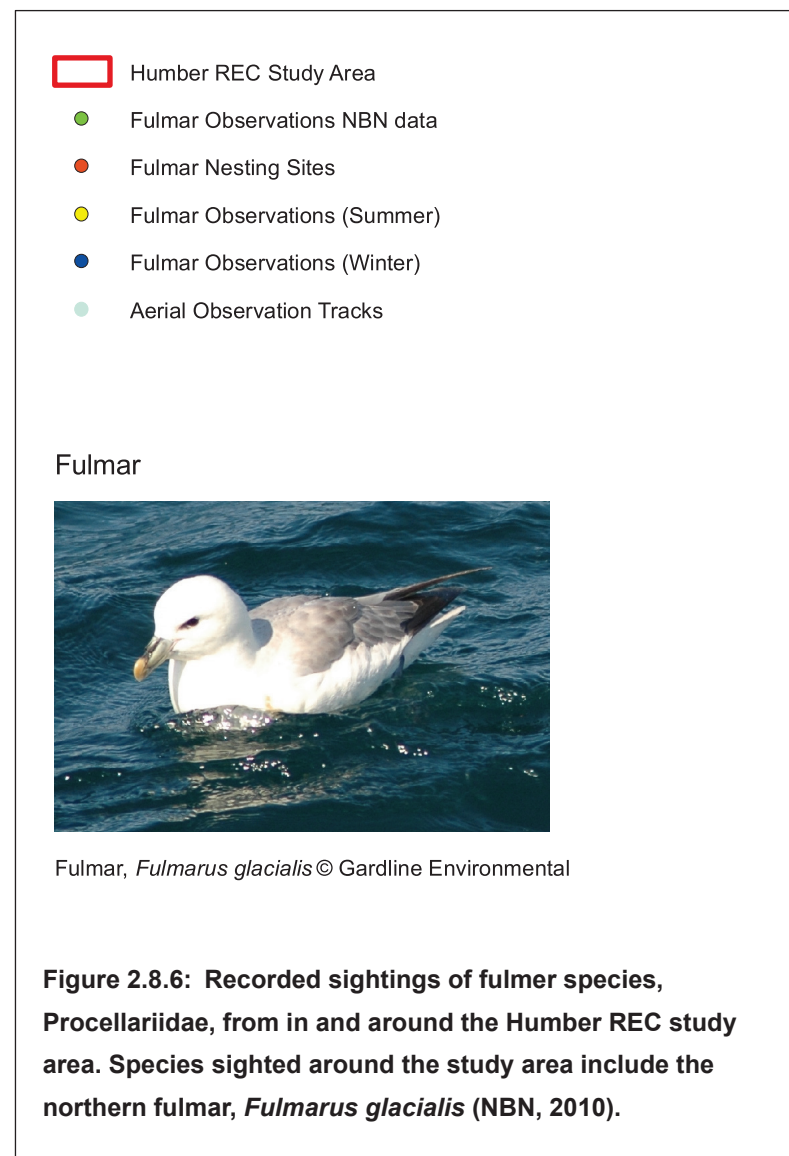
The divers are a small group of relatively large waterbirds, they exploit and breed in freshwater habitats for most of the year but use coastal areas during the winter months for food and shelter (RSBP 2009). Data from NBN (pale green on Figure 2.8.5) are concentrated inland around coastal regions. Aerial surveys show a clustering of divers to the south of the Humber region indicating resources in this area are ample.

The red-throated diver, *Gavia stellata*, is the smallest bird in the diver family and has grey plumage and displays a distinctive

red throat during the summer months. This species can be seen in the Humber area during the winter months (RSBP 2009). Over 900 wintering individuals have been estimated to use the Humber, Wash and adjacent coast during 1995 to 2000 (O'Brien *et al.* 2008). The red-throated diver is listed under Annex 1 of the EU Birds Directive and an amber listing under the Birds of Conservation Concern (Gibbons *et al.* 2009; O'Brien *et al.* 2008; JNCC. 2008).

The great northern diver, *Gavia immer*, has a winter plumage of light brown with a white neck which changes to dark brown with

paler marking during the summer. It is the largest of the divers found in the UK and ventures further offshore (RSBP 2009). The great northern diver can be found in the Humber area during the winter months, before flying back to its breeding grounds in Iceland and Greenland (RSBP 2009). At least 20 percent of the European non-breeding population of the great northern diver is found in the UK giving it an amber listing under the Birds of Conservation Concern (Gibbons *et al.* 2009). This species is also listed under Annex 1 of the EU Birds Directive.

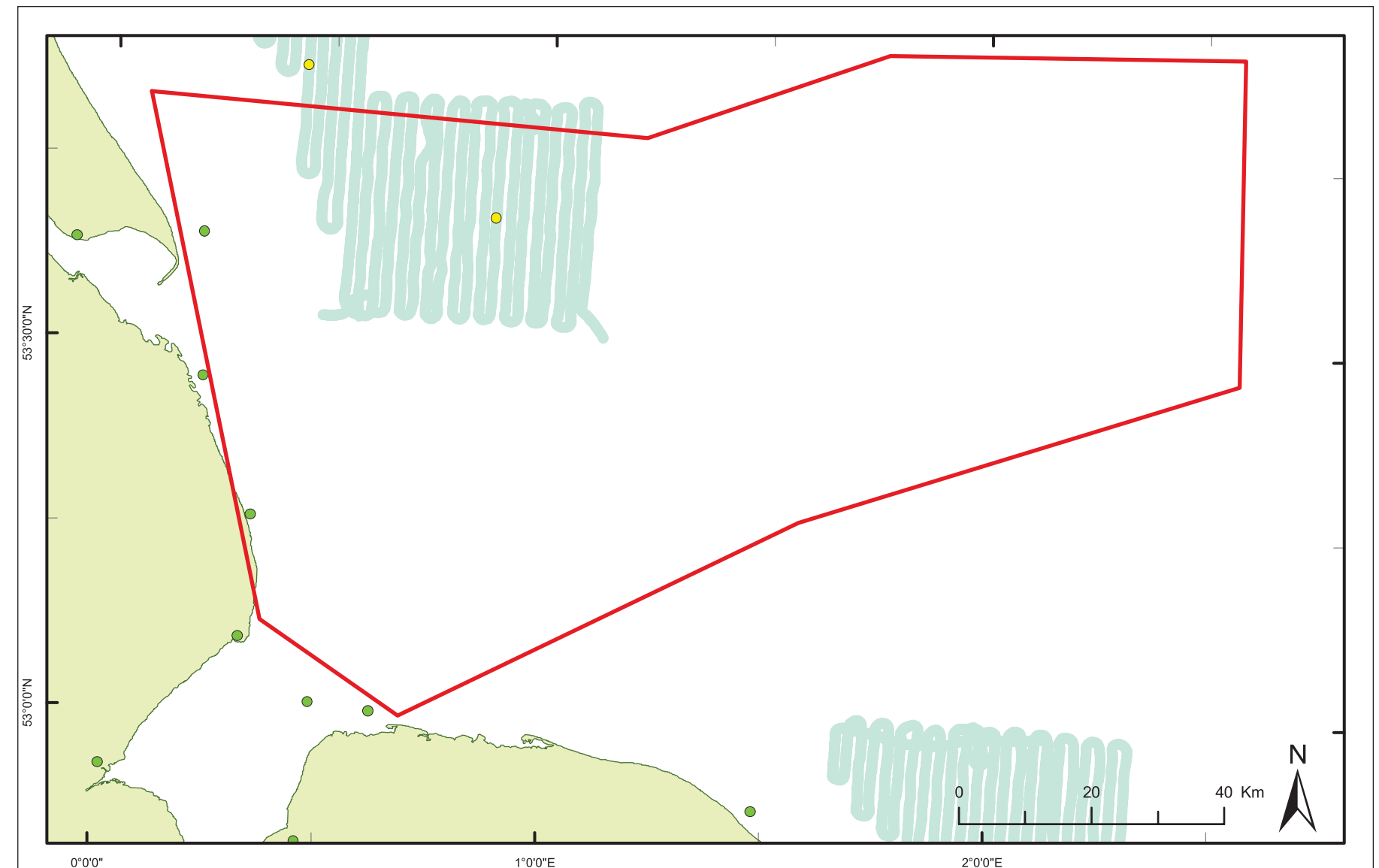
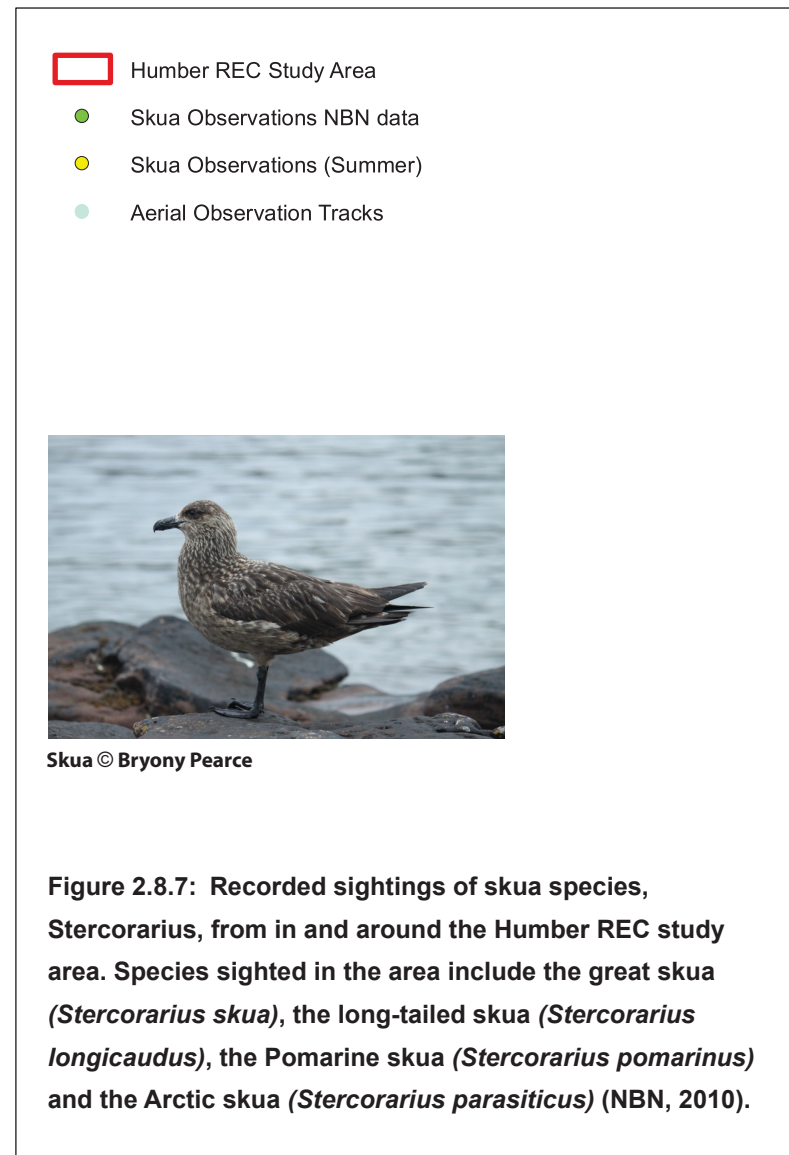


Fulmar — Procellariidae

The fulmars belong to a group of seabirds known as the petrels and shearwaters (Figure 2.8.6). These birds are related to the albatross and are characterised by their unique nostril arrangement

that gives them their nick-name 'tube-noses' (RSBP 2009). The northern fulmar, *Fulmarus glacialis*, can be found in the Humber region all year but the species only ventures inland during the breeding season, Figure 2.8.6. Observations of nest sites are

concentrated south of the Humber Estuary. The northern fulmar nests on cliff ledges often on islands and once fledged they will spend between 4 and 5 years at sea. They will return to a breeding colony at around nine years old (Parkin & Knox 2010).



Skua — *Stercorarius*

The skua family includes four species that frequent the UK. These species are the great skua (*Stercorarius skua*), the long-tailed skua (*Stercorarius longicaudus*), the Pomarine skua (*Stercorius pomarinus*) and the Arctic skua (*Stercorarius parasiticus*). The Arctic Skua and great skua are famed for their keftoparasitism, chasing

down other birds in order to steal their food (RSBP 2009). Only the Arctic skua is considered threatened (Parkin & Knox 2010). Over the past 25 years there has been a 50% decline in UK breeding populations that has pushed the Arctic skua from green to red status under the Birds of Conservation Concern (Gibbons *et al.* 2009).

In the UK Arctic skua breeding sites are restricted to Scotland but migrating birds can be seen in the Humber area (Figure 2.8.7), mainly during the autumn, on passage to their feeding grounds in the southern hemisphere (Parkin & Knox 2010; RSBP 2009).

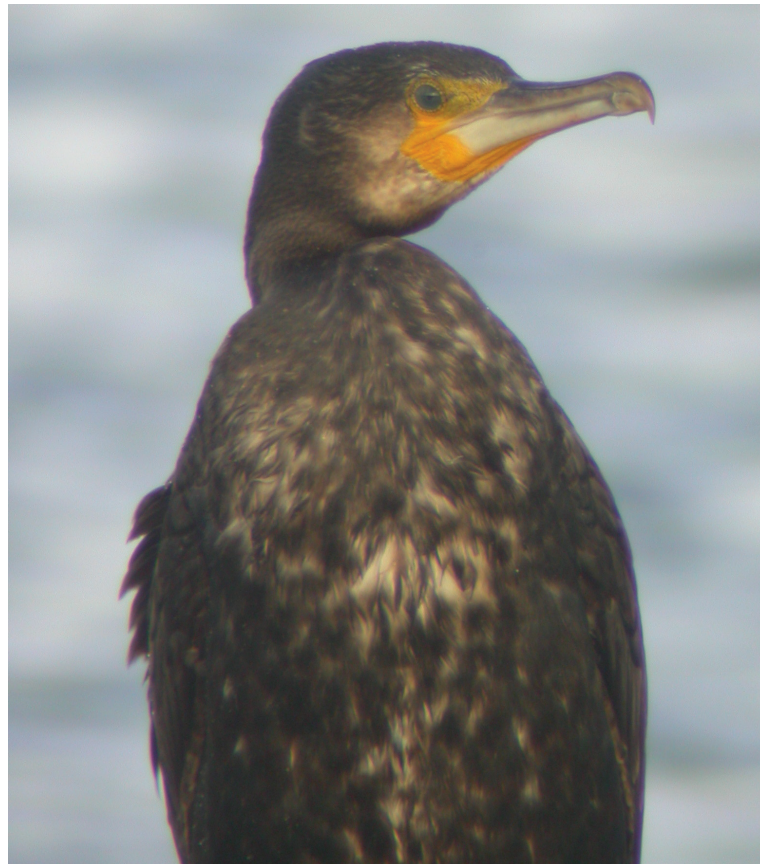
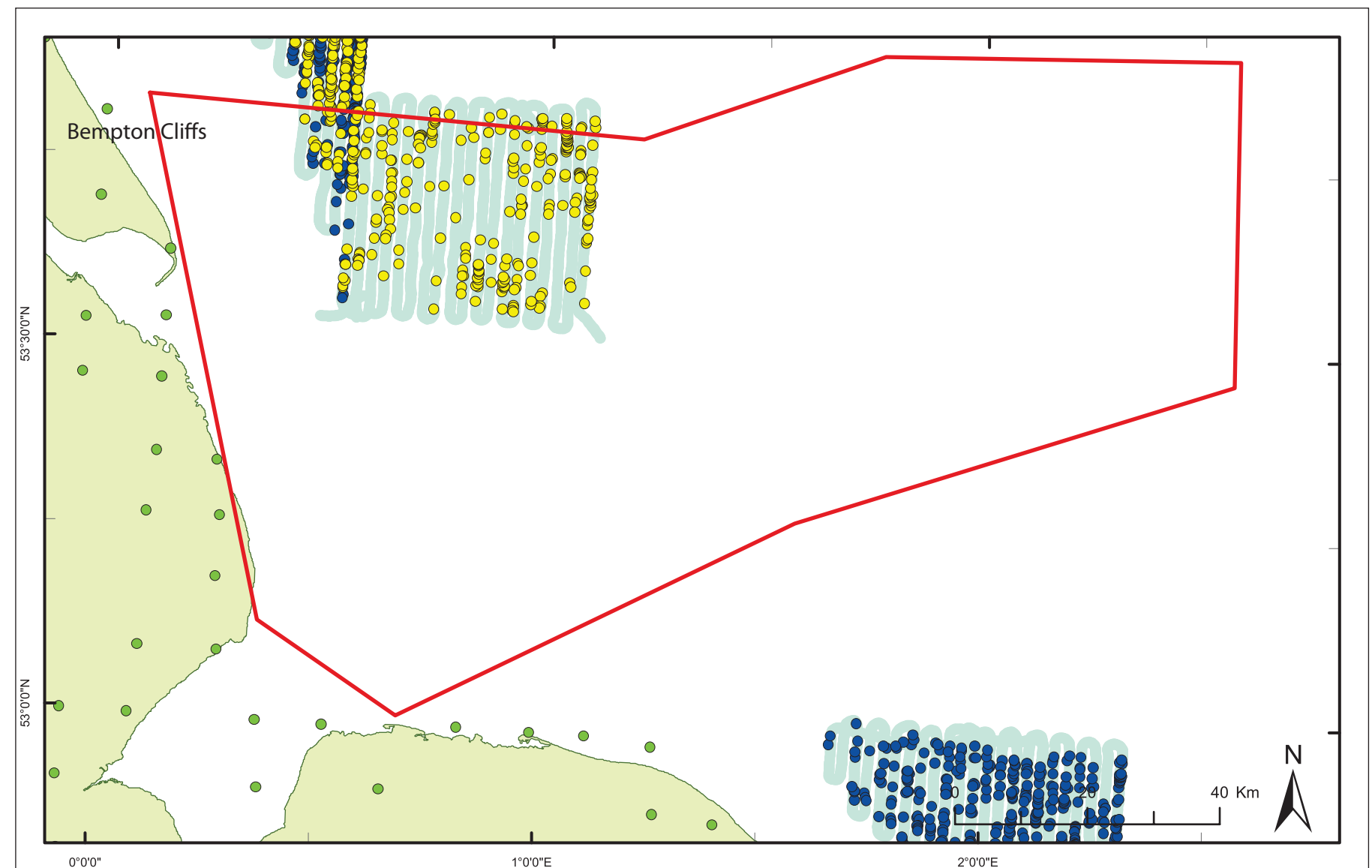
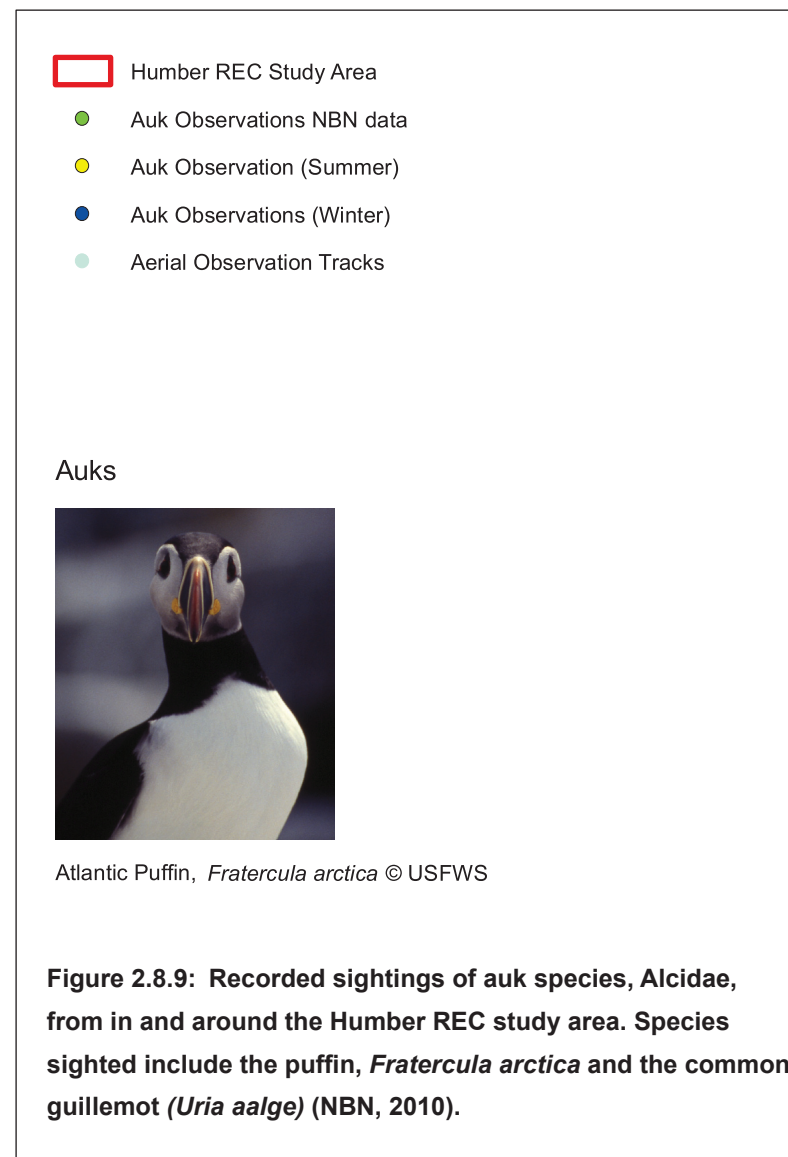


Figure 2.8.8: A Cormorant © Guardline Environmental.

Cormorants — *Phalacrocoracidae*

The cormorant is a large, distinctive bird with striking black plumage and a long neck (Figure 2.8.8) (Kirby *et al.* 1996; RSBP 2009). There are two races of the Great Cormorant, *Phalacrocorax carbo*, the 'Atlantic race' (*P.c.carbo*) and the 'Continental race' (*P.c. sinensis*). Both were traditionally only found in coastal areas but the Atlantic race has now spread inland to freshwater habitats. They are accomplished fishers often coming into conflict with anglers. A steady rise in numbers since the 1970s has led to calls by anglers to control population sizes. However, this species is protected under the Wildlife and Countryside Act (1981), although they can be killed under licence (Bearhop *et al.* 1999). Cormorants do not venture far from land, which is reflected in there being no sightings off the coast, a map for this species has not been included as there were only a couple of recorded nest sites in the Humber area.



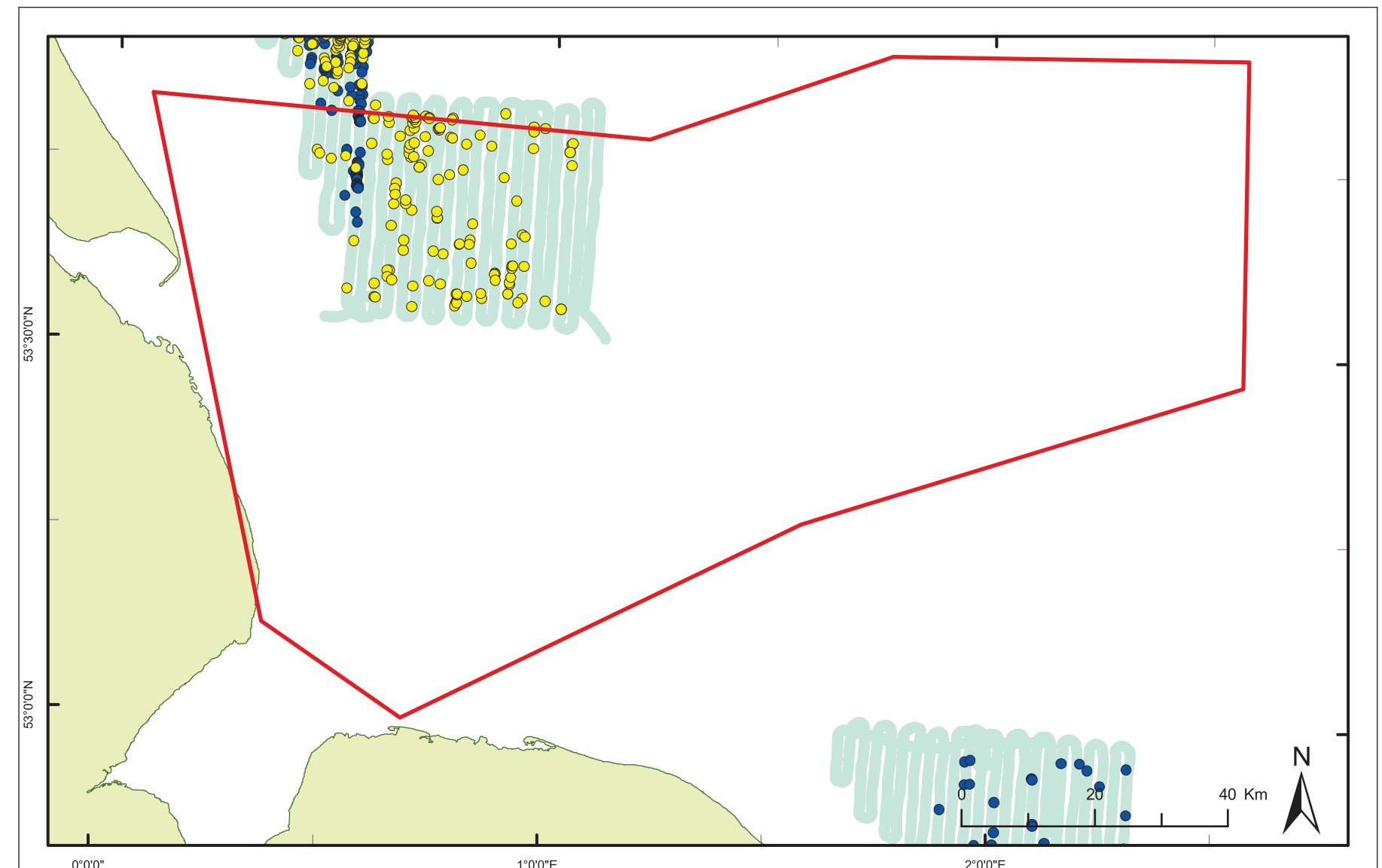
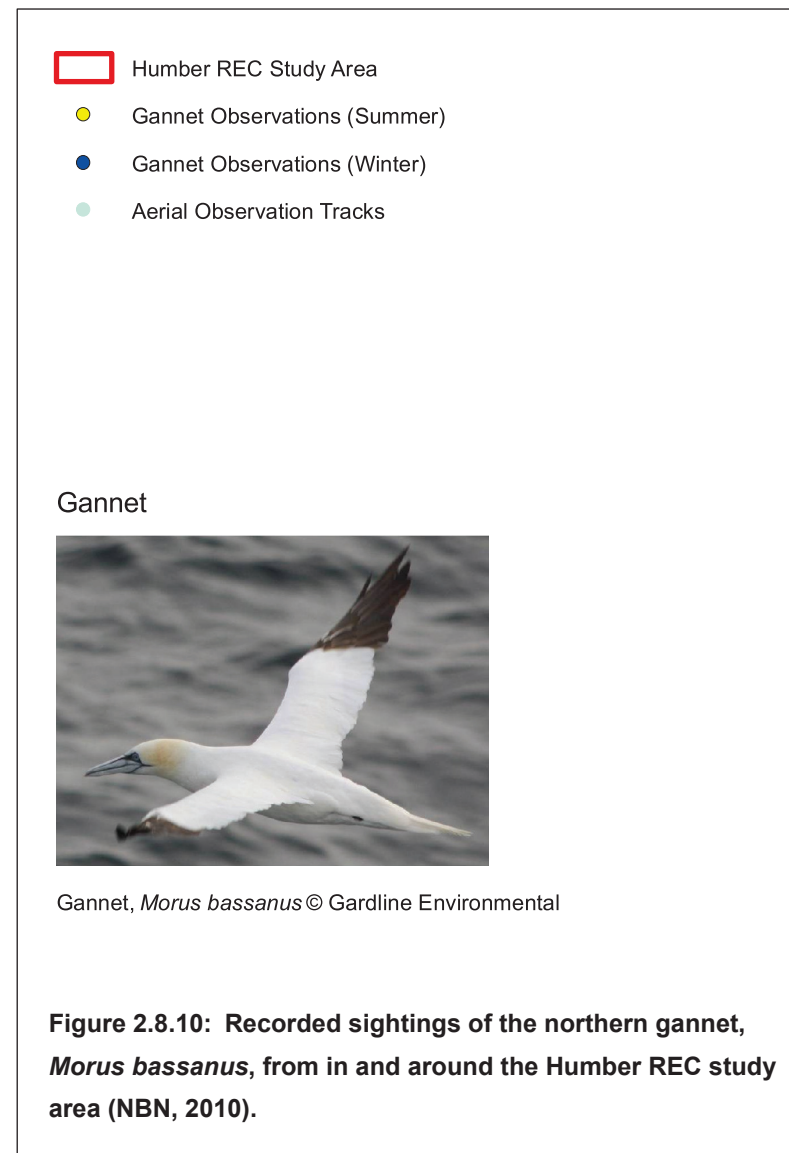
Auks — Alcidae

The Auks are a group of medium sized black and white birds, often described as penguin-like in appearance (RSPB 2009). They have a short wing span relative to body mass so walk and fly awkwardly but are excellent divers and underwater swimmers (Barrett *et al.* 2006). There are many observations of auks in the Humber area, particularly north of Humber Estuary at Bempton Cliffs (Figure 2.8.9). There are numerous observations recorded at Bempton Cliffs as it is the site of an RSPB visitors centre. Most auks spend the majority of their time at sea and this is reflected in the high density of sightings in aerial surveys.

The puffin, *Fratercula arctica* (see photo in Figure 2.8.9), is one of the most recognisable auks with a distinctive orange, black and yellow bill. Puffins only venture onto land to breed, predominately using islands and inaccessible cliff ledges, where they excavate burrows (RSPB 2009). There is a breeding colony of puffins at Bempton Cliffs (Figure 2.8.9). At least 50% of the UK breeding population is found at fewer than ten sites and so puffins have been categorised as amber status under the Birds of Conservation Concern listing (Gibbons *et al.* 2009).

The common guillemot (*Uria aalge*) also breeds at Bempton Cliffs during the summer months and over-winters offshore (RSBP

2009). This species is one of the most abundant seabirds to be found in UK colonies but numbers have been in decline since 2000 and common guillemots are listed as amber under the latest Birds of Conservation Concern (Sims *et al.* 2006; Gibbons *et al.* 2009). The razorbill, *Alca torda*, which also has an amber listing, can be found at colonies around the Humber region but those south of the Humber Estuary (to the Isle of Wight) are non-breeding (Gibbons *et al.* 2009).



Gannets — *Sulidae*

The northern gannet, *Morus bassanus*, is a large white bird with long wings and black wing-tips. They are often seen flying in small groups, flying low over the water before plunge diving for prey (RSBP 2009). Gannets nest in large colonies on cliff ledges and overhangs and have a mean life expectancy of around 16 years (Nelson 1966). The largest breeding colony of northern gannets can be seen during the spring at Bempton Cliffs and offshore observations are common all year round (Figure 2.8.10). Foraging trips of the northern gannet, primarily for pelagic fish and squid, can be up to 540 km out to sea (Hamer *et al.* 2000; Montevecchi

& Myers 1997; Camphuysen, Heessen & Winter 1995). Northern gannets have been categorised as amber under the Birds of Conservation Concern listing as over 20% of the UK breeding population are located in less than ten UK sites (Parkin & Knox 2010; Gibbons *et al.* 2009).

2.9 Areas of Conservation Importance

2.9.1 Nature Conservation

The coastal margins and waters of the Humber region are host to a number of protected sites of national and international

nature conservation importance. In the UK there are several different types of conservation and protected areas, each of which addresses different conservation and legislative priorities. A brief summary of the different protected area found in marine and coastal environments is summarised in Table 2.9.1.

The Joint Nature Conservation Committee (JNCC) is a public body with overall responsibility for the delivery of the UK and international conservation responsibilities of the four country nature conservation agencies — the Council for Nature Conservation and the Countryside Northern Ireland (CNCCNI), the Countryside

Designation	Abbreviation	Legislation	Importance	Focus of protection
Special Areas of Conservation	SAC	European Habitats Directive (92/43/EEC)	European	Habitats and species (as listed under Annex I and Annex II of the Directive)
Special Protection Areas	SPA	Birds Directive (2009/147/EC)	European	Birds and habitats used by birds (bird species specified in Annex I of the Directive)
Ramsar Sites	Ramsar	Convention on Wetlands of International Importance (1971)	International	Wetlands utilised by birds
Sites of Special Scientific Interest	SSSI	Wildlife and Countryside Act (1981)	National	Species, habitats and geological features of national importance
National Nature Reserves	NNRs	Wildlife and Countryside Act (1981)	National	Best UK examples of SSSIs - species, habitats and geological features of national importance
Marine Nature Reserves	MNR	Wildlife and Countryside Act (1981)	National	Marine flora and fauna and geological / physiographical features of special interest (e.g. Lundy Island) – to be replaced by MCZs
Marine Conservation Zones	MCZ	The Marine and Coastal Access Act (2009)	National	Nationally important marine wildlife, habitats, geology and geomorphology. The focus will extend to include examples of the full range of UK marine wildlife
No Take Zone	NTZ	XXVII Flamborough Head No Take Zone — bylaw enacted by the North Eastern Sea Fisheries Committee	Local	The functionality of the ecosystem
Voluntary Marine Conservation Area	VMCA	N/A	Local	Areas of coastline which are of particular wildlife and scientific value that enjoy a level of voluntary protection. These are often extensions of statutory, terrestrial or coastal designations.

Table 2.9.1: Summary of marine and coastal conservation designations in the UK, their underlying legislation, level of importance and protection focus.

Council for Wales (CCW), Natural England (NE) and Scottish Natural Heritage (SNH). Each agency is responsible for delivering nature conservation to meet the requirements of the three key pieces of UK conservation legislation — the European Habitats Directive (1992), the European Wild Birds Directive (1979) and the Wildlife and Countryside Act (1981). Each organisation has a duty to designate Special Areas of Conservation (SACs), Special Protection Areas (SPAs) and Sites of Special Scientific Interest (SSSIs) where specified threatened habitats and species occur. Furthermore, as a signatory to the Ramsar Convention (1971) in 1976 the UK government is obliged to designate wetlands of international significance as Ramsar sites. Other nationally and locally important marine resources are protected through designations such as Marine Nature Reserves (MNR) National Nature Reserves (NNR) and No Take Zones (NTZ).

As a member of the European Union the UK has an obligation to establish an 'ecologically coherent network of Marine Protected Areas (MPAs)' by 2012 under the European Marine Strategy Framework Directive (2008). This network of protected sites will be made up of existing Marine Protected Areas (MPAs) including current SACs and SPAs together with a new type of MPA called Marine Conservation Zones (MCZs) which will be designated under the Marine and Coastal Access Act (2009). The MPA network aims to deliver protection for the best examples of all of the marine habitats found across UK waters and to ensure that these habitats will be capable of sustaining themselves over the coming decades. The project tasked with designing the network of MPAs and MCZs is 'Net Gain' (www.netgainmcz.org/) which covers the whole of the North Sea.

Many threatened habitats and species occur across the Humber REC area, hence a number of protected sites have been

established in the region. Some areas have received multiple designations, with other areas receiving one designation for more than one reason. Maps of the designated sites which occur in and around the Humber REC area are presented in Figures 2.9.1 and 2.9.2. Figure 2.9.1 illustrates the distribution of conservation designations of European importance, namely the SPAs, Ramsar Sites, SACs and Possible SACs (pSACs) and Potential SPAs (pSPAs) across the Humber region. For ease of use, since there is often overlap between designations, the distribution of SSSIs and NNRs (within a km of the coastline), are shown separately in Figure 2.9.2.

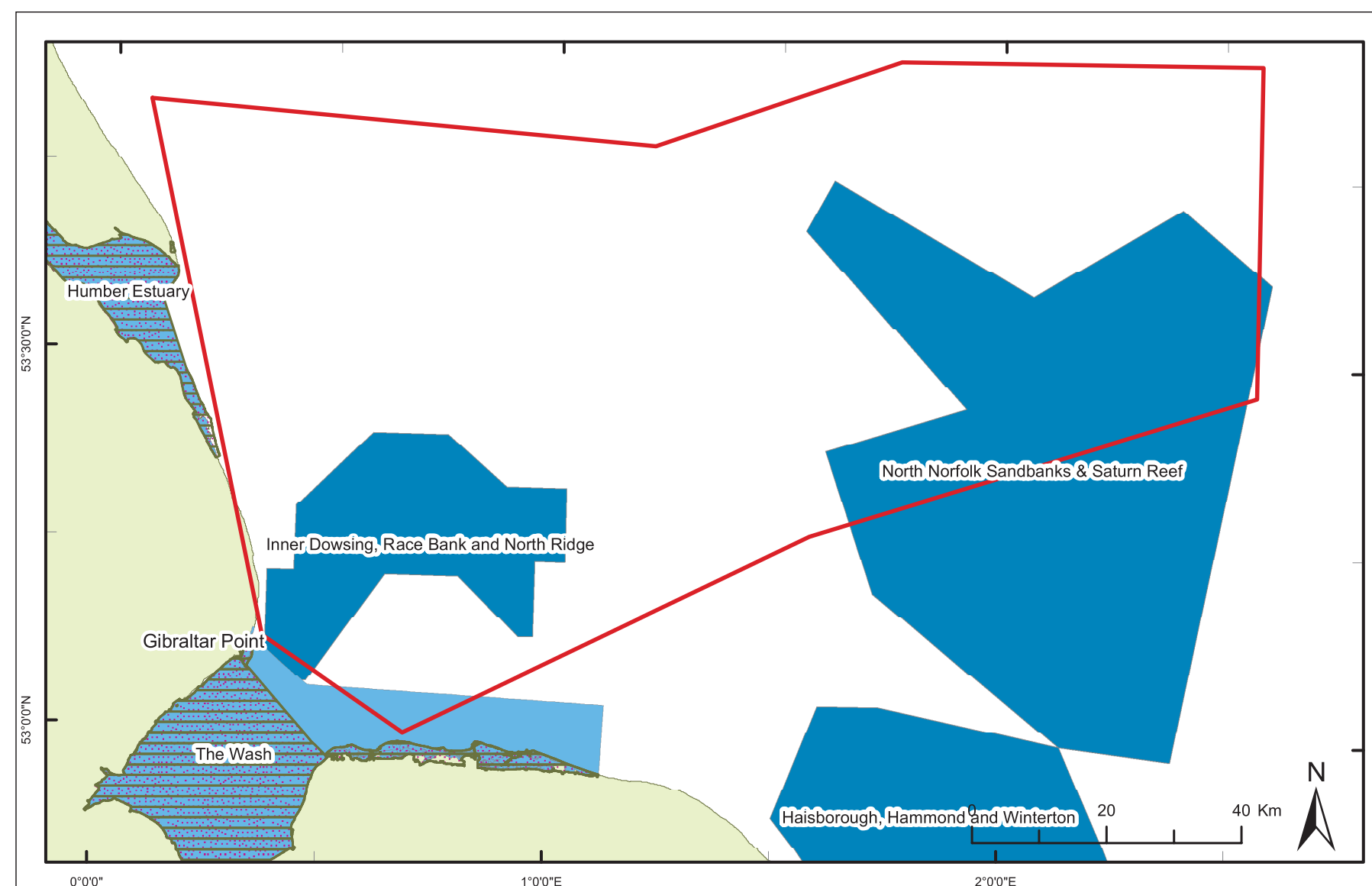
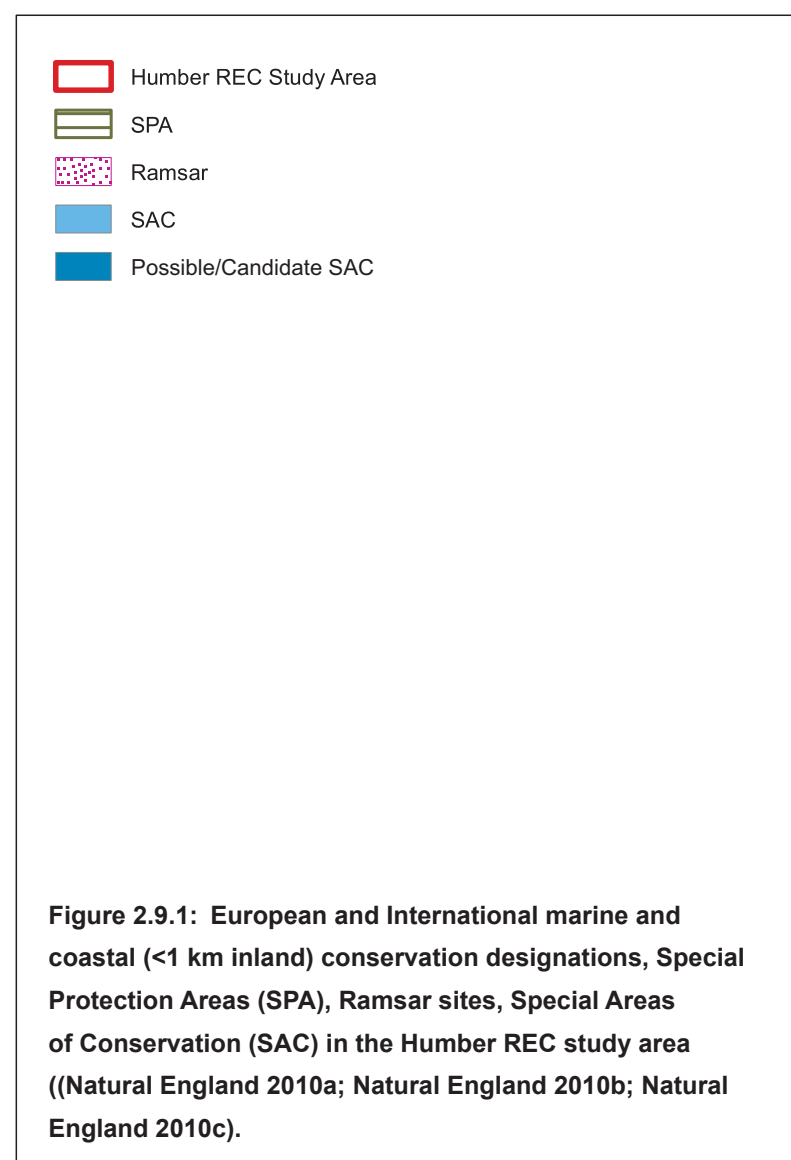
2.9.2 Protected Sites of International and European Importance

A number of internationally important protected sites are found in the immediate vicinity of the Humber REC area (Natural_England, 2009a, b, c) (Figure 2.9.1). The number of designations reflects the level of ecological diversity found across the area of interest, which contains expanses of open sea, a wide variety of different types of coastline which includes areas of estuary, harbours, woodlands, heath, and many different types of wetland and other habitats — many of which support internationally important populations of many different species.

A total of fourteen internationally important sites have been designated across the Humber region: five SACs, five SPAs and four Ramsar sites although the overwhelming majority of these sites are either coastal with marine elements or terrestrial. There are also a further 3 possible SACs (pSACs) in the area. Important sites often have a number of features of both national and international importance and so an area of land may hold a number of different designations. Each of the internationally important sites are shown in Figures 2.9.1 and 2.9.2.

Flamborough Head SAC

The Flamborough Head SAC lies to the north of the Humber REC zone and covers an area of 6 311.96 ha of coastal cliffs, intertidal areas and inshore marine waters. Approximately 80% of this SAC is classified as marine with the remaining 20% classified as coastal/terrestrial. The three key features of this SAC, which are listed under the European Habitats Directive (1992), are



Reefs, Vegetated Sea Cliffs of the Atlantic and Baltic Coasts and Submerged or Partially Submerged Sea Caves.

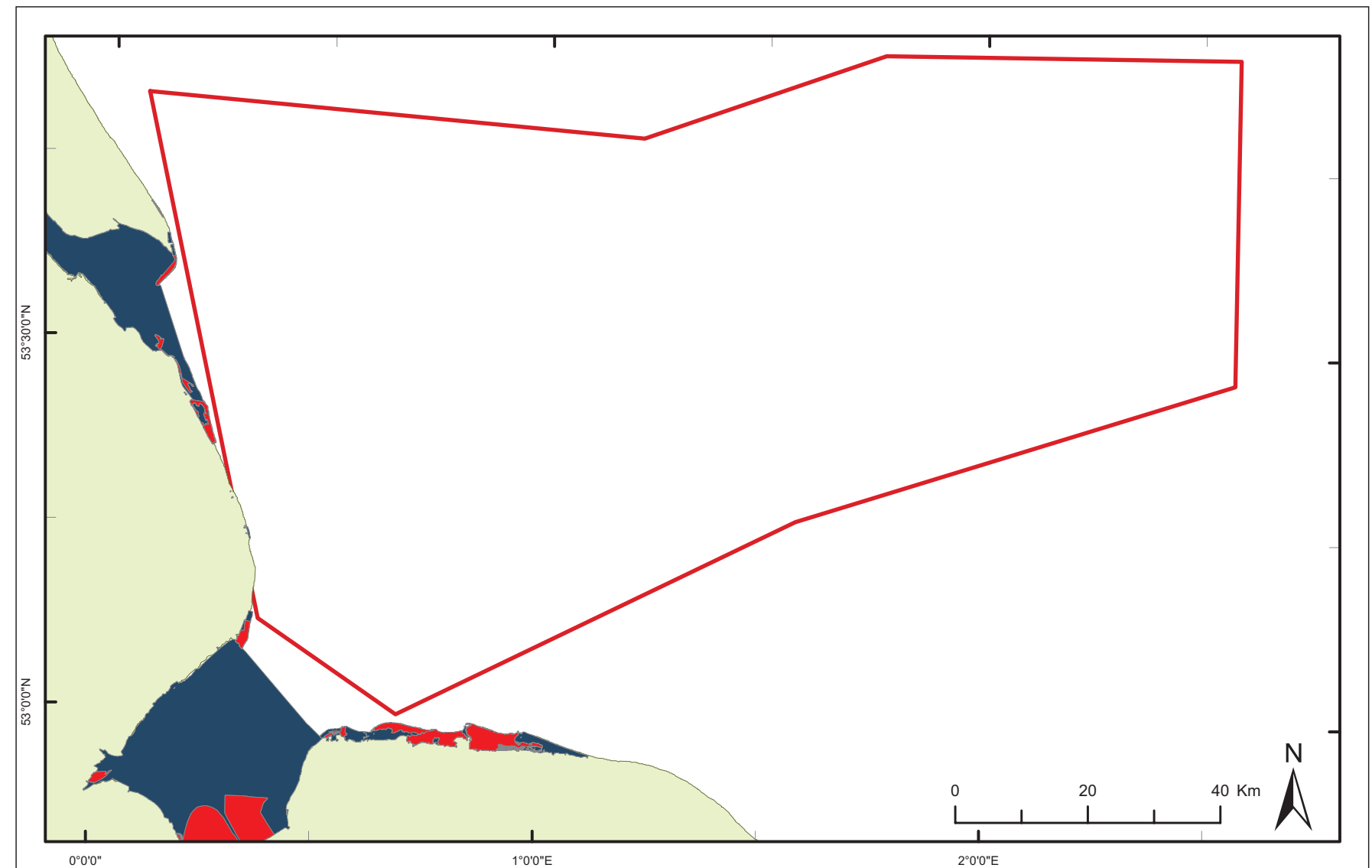
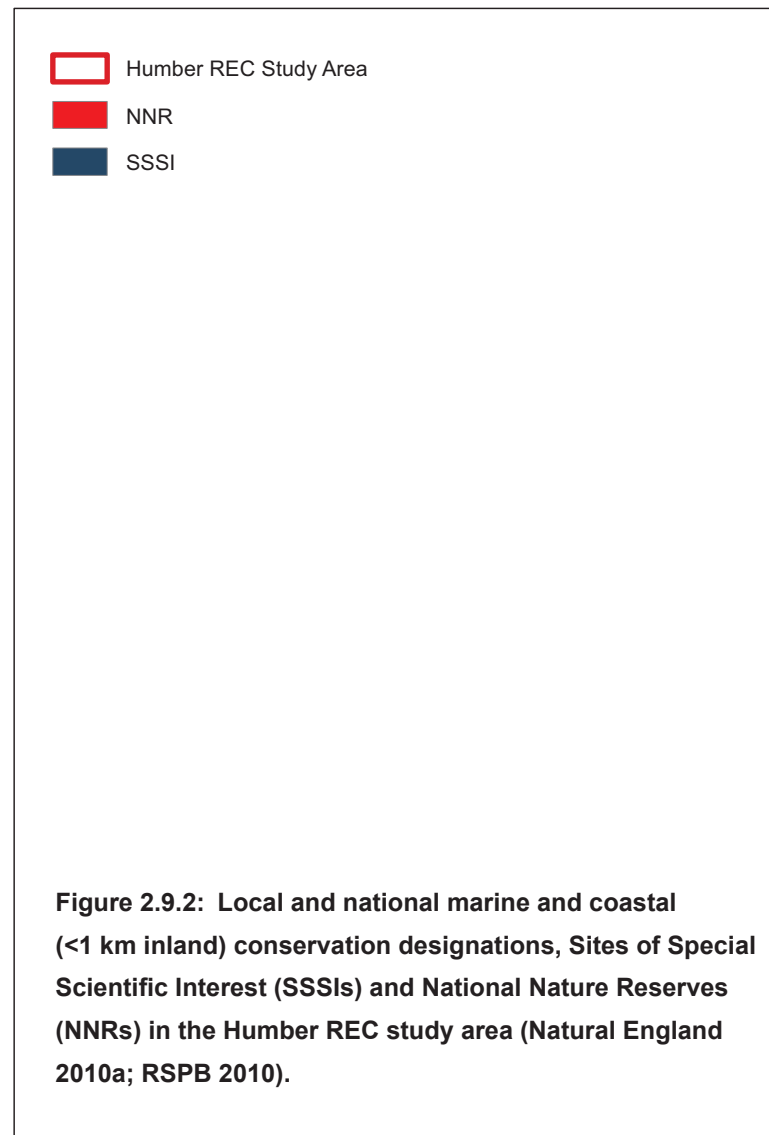
The Flamborough Head SAC lies close to the biogeographic boundary between the northern and southern regions of the North Sea and is situated at the southern limit of distribution of a number of species which are usually associated with more northerly latitudes. The benthos of this site is composed of large areas of both hard and soft chalk and it has been estimated that this area contains 14% of the UK's coastal chalk exposures and represents the UK's most northerly outcrop of chalk. The hard chalk cliffs

are host to important communities of calcareous cliff vegetation. Excellent examples of maritime vegetation occur in areas which are exposed to salt spray with examples of calcareous, mesotrophic and acidic grassland communities also occurring across the site.

The Flamborough Head SAC also contains areas of topographically complex bedrock and boulder reefs which extend into relatively deep waters. The relatively unpolluted waters found in the Flamborough area, combined with the relative clarity of the waters, have contributed to the development of *Laminaria hyperborea* forests in the shallow subtidal zone. The diverse array

of relatively rare habitats found across the Flamborough Head SAC has allowed complex mosaics of rich fauna to develop, with the sublittoral and littoral reef habitats found at Flamborough held by many authorities as the most diverse in the UK.

A large number of submerged and partially submerged sea caves are found within the Flamborough Head SAC, with these caves supporting a range of different cave habitats. There are over 200 caves within the boundaries of the site, with the largest known to extend 50 m from mouth to terminus. Many of the Flamborough caves are host to specialised algal communities consisting



of species such as *Hildenbrandia rubra*, *Pseudendoclonium submarinum*, *Sphacelaria nana* and *Waerniella lucifuga*.

Given the range of different habitats found at the site, the range of niches present within these habitats and the relatively unique location of the areas at a biogeographical boundary it is evident that the Flamborough Head SAC is conservation site of great importance.

Humber Estuary SAC

The Humber Estuary SAC covers an area of just over 36 000 ha, with the majority of the site comprising mudflats, sandflats, lagoons and the River Humber itself (Figure 2.9.1). Areas of salt

marsh, sand dunes and bogs, marshes and fens also occur. The designated features of the Humber Estuary SAC are Estuaries and Mud Flats and Sand Flats not Covered by Seawater at Low Tide. A further eight qualifying features are also present, although these are not the primary reason for designation.

The Humber Estuary is an important conservation site as it is the second largest coastal plain estuary in the UK and the largest on the east coast. The Humber Estuary is a muddy, macro-tidal estuary fed by a number of tributary rivers including the Trent and the Ouse amongst others. Salt meadows, intertidal sandflats and mudflats and submerged sandflats and mudflats are found

across the seaward reaches of the estuary. These coastal, marine influenced habitats are gradually replaced by brackish salt marsh communities and reedbeds as salinity decreases upstream. Significant populations of the river lamprey *Lampetra fluviatilis* and sea lamprey *Petromyzon marinus* are known to breed in the River Derwent, a tributary of the Ouse.

The Wash and North Norfolk Coast SAC

The Wash and North Norfolk Coast SAC is large, covering over 100 000 ha of marine waters, tidal estuaries and saltmarsh (Figure 2.9.1). The area covered by this SAC extends into the southeast of the Humber REC area. This SAC has been designated in order to

provide protection for a total of eight primary features:

- Sandbanks which are slightly covered by sea water all the time
- Mudflats and sandflats not covered by seawater at low tide
- Large shallow inlets and bays
- Reefs
- Salicornia and other annuals colonising mud and sand
- Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)
- Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticosi*)
- Common seal *Phoca vitulina*

The presence of Coastal Lagoons and the otter *Lutra lutra* are additional qualifying features.

The sheer diversity of extensive marine and coastal habitats found across this site make this SAC an extremely valuable nature conservation resource.

Saltfleetby–Theddlethorpe Dunes and Gibraltar Point SAC

This site hosts a number of internationally important ecological features including shifting dunes along the shoreline with *Ammophila arenaria*, fixed dunes with herbaceous vegetation, dunes with *Hippophae rhamnoides* and humid dune slacks.

Flamborough Head and Bempton Cliffs SPA

This site supports breeding populations of European importance of the kittiwake *Rissa tridactyla*. During the breeding season there are 83 370 pairs of kittiwakes in this area, representing at least 2.6% of the breeding Eastern Atlantic — breeding population.

Humber Estuary SPA

The Humber Estuary SPA covers almost 40 000 ha of estuarine and coastal environments. This site encompasses an extensive array of diverse habitats which support a number of internationally important bird populations breeding and over-wintering in the area. The Humber Estuary is host to populations of bittern, marsh harrier, avocet, little tern, dunlin, red knot amongst many other internationally important waterfowl and wader species which forage across the mudflats, sandflats lagoons and salt marshes which are

found across the site. The boundaries of the Humber Estuary SPA coincide with the boundaries of the Humber Estuary Ramsar site.

Gibraltar Point SPA

This SPA contains a number of different habitats which support internationally important populations of a small number of bird species at different times of the year. The key species which are found at this site are the sanderling, the little tern, the bar-tailed godwit and grey plover. The boundaries of the Gibraltar Point SPA coincide with the boundaries of the Gibraltar Point Ramsar site.

The Wash SPA

The Wash SPA covers over 62 000 ha of coast line between northern Norfolk and eastern Lincolnshire. This extensive site primarily comprises an inlet of the sea and a variety of sandflats and mudflats which provide excellent foraging habitats for both breeding and overwintering birds. The key species which occur are the little tern, the common tern, the bar-tailed godwit, the northern pin-tail, wigeon, pink-footed geese and the common goldeneye. The boundaries of the Wash SPA coincide with the boundaries of the Wash Ramsar site.

North Norfolk SPA

The North Norfolk SPA comprises a rich mosaic of habitats which also supports a number of important bird species including the bittern, the avocet, the sandwich tern and the pink-footed goose. The boundaries of the North Norfolk SPA coincide with the boundaries of the North Norfolk Ramsar site.

Ramsar Sites

These designations which include the Humber Estuary, Gibraltar Point, The Wash and the North Norfolk Coast have boundaries that coincide with the designations discussed above.

2.9.3 Draft Nationally Important Conservation Sites

Natural England and the JNCC are currently in the process of designating further SACs in the offshore waters in and adjacent to the Humber REC study area and three further sites have been put forward for designation. Two sites are Possible SACs (pSACs) and one has been passed onto the next stage and so is now referred to as a Candidate SAC (cSAC). One of these site falls largely within the Humber REA area, with the other lying south and east of the area of

interest. A third site has yet to be put forward for public consultation by the JNCC. The proposed SACs are briefly described below, and are shown in Figure 2.9.1.

Inner Dowsing, Race Bank and North Ridge Candidate SAC

This site has been scheduled for designation in order to provide protection for the important, permanently submerged sandbanks and biogenic *Sabellaria spinulosa* reefs which are found across the area. This site lies entirely within the Humber REC study area and straddles the 12 nautical mile boundary. A range of different sand bank types are found across the proposed SAC, with banks bordering channels, linear relict banks and sinusoidal banks with distinctive subsidiary banks all represented. The areas which lie between the sand banks primarily comprise gravelly sands which are functionally linked to the sand banks themselves. These areas support a diverse mosaic of habitats which contribute to the importance of the site. Areas of *Sabellaria spinulosa* reef are found across the proposed site, with two primary reefs occurring at Lynn Knock and Docking Shoal. These areas of reef further enhance the importance of the site as such features are known to support abundant assemblages of diverse fauna.

North Norfolk Sandbanks and Saturn Reef Possible SAC

The North Norfolk Sandbanks consist of 10 main sandbanks and a number of smaller banks, which collectively form the most extensive example of offshore linear ridge sandbanks in UK waters. The banks are home to diverse communities of invertebrates typical of sandy sediments. Saturn reef is a biogenic reef created by the tube building ross worm *Sabellaria spinulosa*.

Haisborough, Hammond and Winterton Possible SAC

This site has been put forward for designation in order to provide statutory protection for the extensive sandbank systems which are found across the inshore waters of northern East Anglia.

2.9.4 Nationally Important Protected Sites

Sites of Special Scientific Interest (SSSIs) are designated in areas which the conservation agencies deem to be 'of special interest by reason of any of its flora, fauna, or geological or physiographical features' (Natural England 2010a). SSSIs are sites which are perceived to be important at a national level. National Natures Reserves (NNRs) are another type of nationally important site

(Natural England 2010a). NNRs are representative of the very best examples of the UK's wildlife habitats and geological features. The habitats found on NNRs are usually managed by a government agency or a proxy organisation such as a local wildlife trust or the RSPB. NNRs are usually open to the public as places for learning and recreation. There are also a limited number of Marine Nature Reserves (MNRs) which have been designated across the UK although none of these exist within the Humber region. A further protected site known as the Flamborough Head No Take Zone is found near the area of interest. This NTZ has been designated in order to fully protect a small area from the ecologically destructive impacts of fishing.

The distribution of SSSIs and NNRs within the Humber region are depicted in Figure 2.9.2. This figure demonstrates that, whilst a large number of these sites occur across the area of interest, relatively few lie wholly within the boundaries of the Humber REC study area and significantly fewer have any association with the marine environment. The UK's second No Take Zone (NTZ) has been established by the Committee for the North Eastern Sea Fisheries District in an area within the Flamborough Head Special Area of Conservation. The NTZ will totally prohibit the removal of sea fish by any method in order to pilot the impact of NTZs on fisheries management.

2.10 Fisheries

Fisheries within the European Union (EU) are managed under the Common Fisheries Policy (CFP) by way of derogation although territorial seas up to the 12 nautical mile limit are managed exclusively by the nation state. In order to promote sustainability of fishing activities and to protect specific stocks in EU waters a number of conservation measures have been introduced under the CFP. These include Total Allowable Catch (TAC) limits and the use of technical measures such as mesh sizes, selective fishing gear, closed areas, minimum landing sizes, and by-catch limits.

The International Council for the Exploration of the Sea (ICES) coordinates and promotes marine research on oceanography, the marine environment, the marine ecosystem, and on living marine resources in the North Atlantic.

The Humber REC area is shared between ICES areas IVb (north) and IVc (south), and is also split between two UK Sea Fishery Committee districts; the North Eastern Sea Fisheries (NESFJC) and the Eastern Sea Fisheries Joint Committee (ESFJC).

Landings data encompassing the REC area has been acquired from the Marine Fisheries Agency (MFA), now part of the new Marine Management Organisation (MMO). This data is based on sub-divisions of the larger ICES rectangles called statistical rectangles (Figure 2.10.1). At the time of writing the 2010 UK quotas have not been fully finalised, and so may be subject to change later in the year.

Commercial fishing in south Yorkshire and north Lincolnshire waters by large vessels, historically concentrated mainly on trawling for plaice, sole, cod, whiting, the Norway lobster, and other whitefish although an increase in potting for crab, lobster and whelk has been seen in recent years (Figure 2.10.2). The majority of these trawlers are otter trawlers, although twin-rig and pair trawling also takes place. A significant winter *Nephrops* fishery is based in the north of the Humber REC study area, which tends to target white fish in the summer months. Dredging, netting and seining also occur. A small number of vessels dredge for scallops and beam trawl for shrimps in the Humber.

In contrast the inshore fishing activities off the Lincolnshire and north Norfolk coast are dominated by smaller demersal trawling boats which principally target shellfish (Figure 2.10.2). Wild and cultivated stocks of molluscs and crustaceans, particularly cockles, whelks, mussels and shrimp, are important in the area. Edible crab, lobster and velvet crabs are targeted at the chalk reefs off the north Norfolk coast and shellfish gatherers are active between Donna Nook and Sheringham (Figure 2.10.1.). Occasionally pelagic trawlers land large quantities of small open ocean species such as herring and sprat when there is a high market demand (Walmsley & Pawson 2007).

2.10.1 Finfish

Fishing for finfish takes place within the Humber REC region although the landings of this group have decreased over the last 20 years (Figure 2.10.3. & Tables 2.10.1 and 2.10.2). This is due to a combination of the depletion of stocks and the introduction of smaller quotas. Silver Pit, in the eastern region of the study area, is a

particularly popular fishing ground and is targeted by beam trawlers (CEFAS & Fisheries Research Services 2001). Different species are caught using different fishing gear. Seine netting targets demersal species mainly in the north of the REC region (such as plaice and cod). Pelagic trawling targets small pelagic fish in the East of the REC area. Demersal trawling takes place throughout the Humber REC area. It is mainly a mixed trawl fishery and the catch includes plaice, sole, cod and whiting along with some shellfish (Figure 2.10.4).

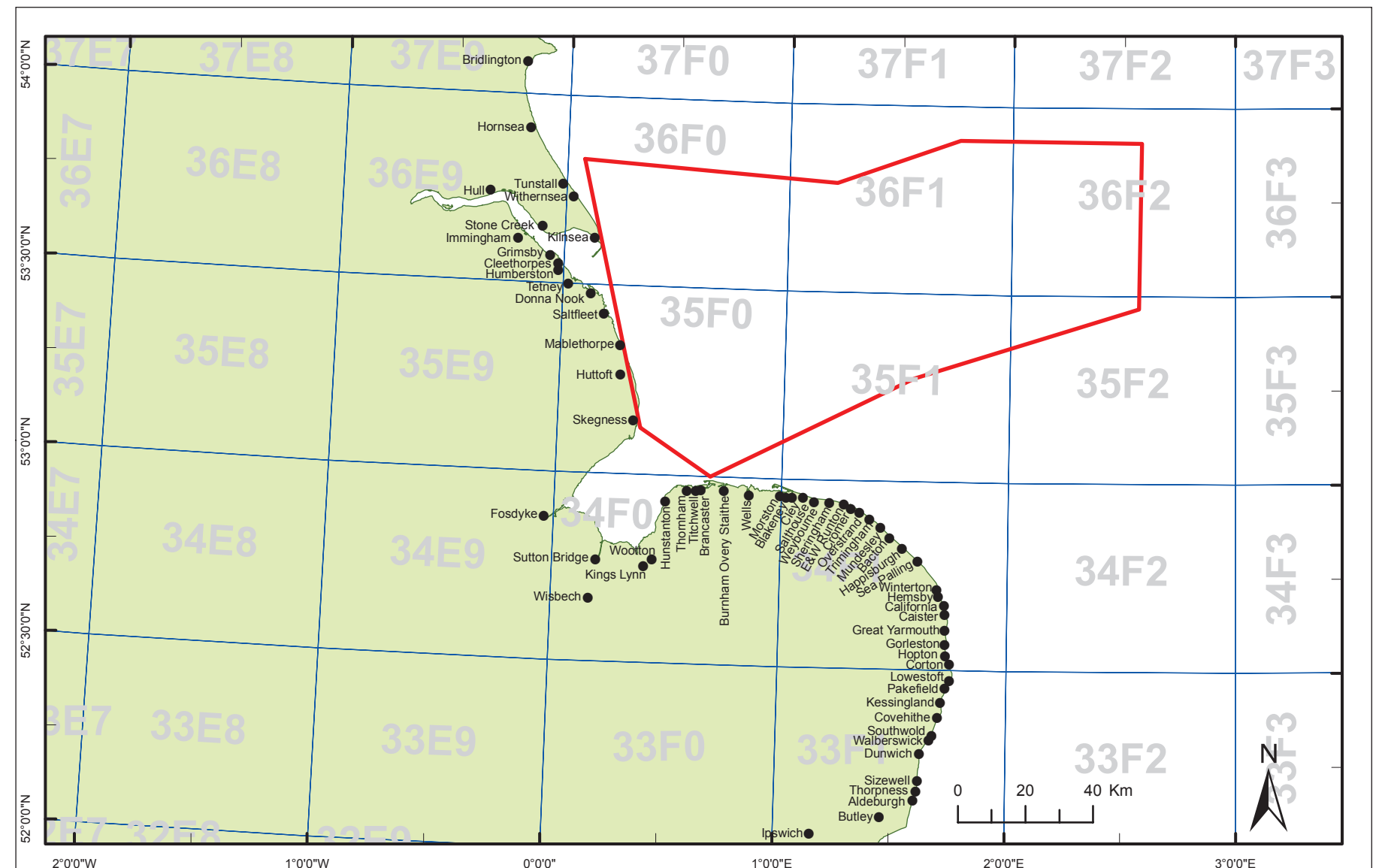
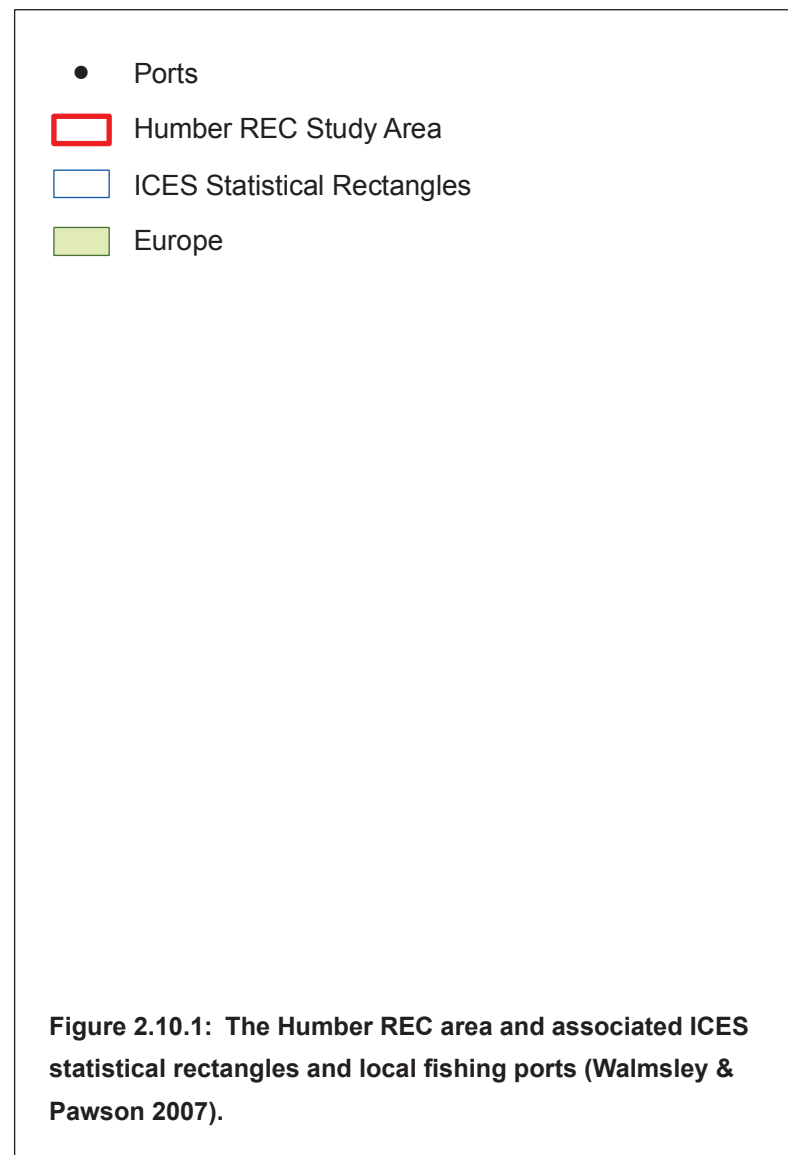
Cod — *Gadus morhua*

The cod, *Gadus morhua*, is historically one of Britain's most important commercial species. It is widely distributed around the UK although fishing pressures mean that it is now less common in our waters. Cod are large, heavily built gadoid fish, which may grow up to 150 cm in length. They have distinct mottled markings along their backs, a prominent lateral line and pronounced chin barbel (see Figure 2.10.5).

Cod are known to migrate to well-defined spawning grounds offshore from early spring (January to April). They tend to spawn in the pelagic zone at depths of about 200 m, although in the North Sea they are known to spawn between 20 m and 100 m. The eggs rise to the surface and drift with ocean currents (Dipper 2001). Females spawn prolifically (Kjesbu 1989), producing between 3 and 6 million eggs in a single spawning event (Trippel 1998).

Cod spend the first half year of their life in the water column, as eggs, larvae, and then metamorphosed juvenile fish. During late winter (February to March) larvae (between 2 and 8 mm) feed predominantly on copepod larvae. Between July and August, once reaching a size of approximately 7 cm, the juveniles migrate to the seabed to take up a 'demersal' or bottom dwelling life-style (Heessen & Daan 1994). At this stage the diet changes to small fish and crustaceans, notably the brown shrimp, *Crangon* sp., and then on to larger fish, many of which are commercially important (Shaw *et al.* 2008; Robb & Hislop 1980). It is generally accepted that once the spawning season is over the juvenile cod drift into coastal nursery areas and young cod can be found in estuaries and shallow waters off Denmark, Germany, Holland and the UK.

The Wash is a recognised cod nursery area where significant numbers of juveniles have been recorded as by-catch from shrimp trawling (Rogers, Milner & Mead 1998). There is also an extensive



coastal nursery north of Spurn Head extending beyond Flamborough Head (Coull, Johnstone & Rogers 1998). Cod are also believed to spawn on offshore wrecks throughout the North Sea and these are known to be abundant within the REC boundary (Fitch 2008). One of the most important predators of juvenile cod is the grey gurnard, (*Eutrigla gurnardus*) which has been shown to be responsible for approximately 60% of the total predation mortality (Floeter *et al.* 2005).

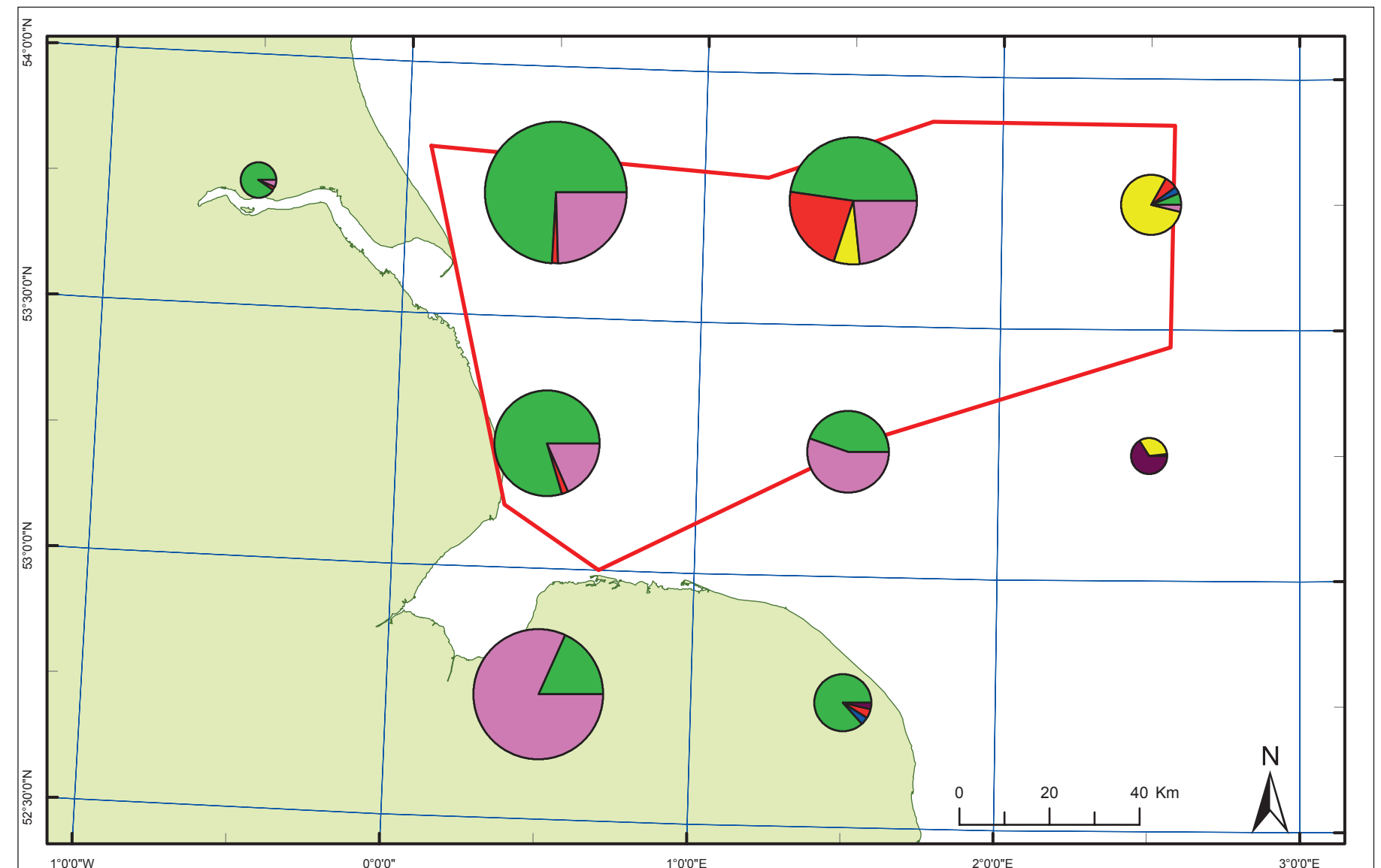
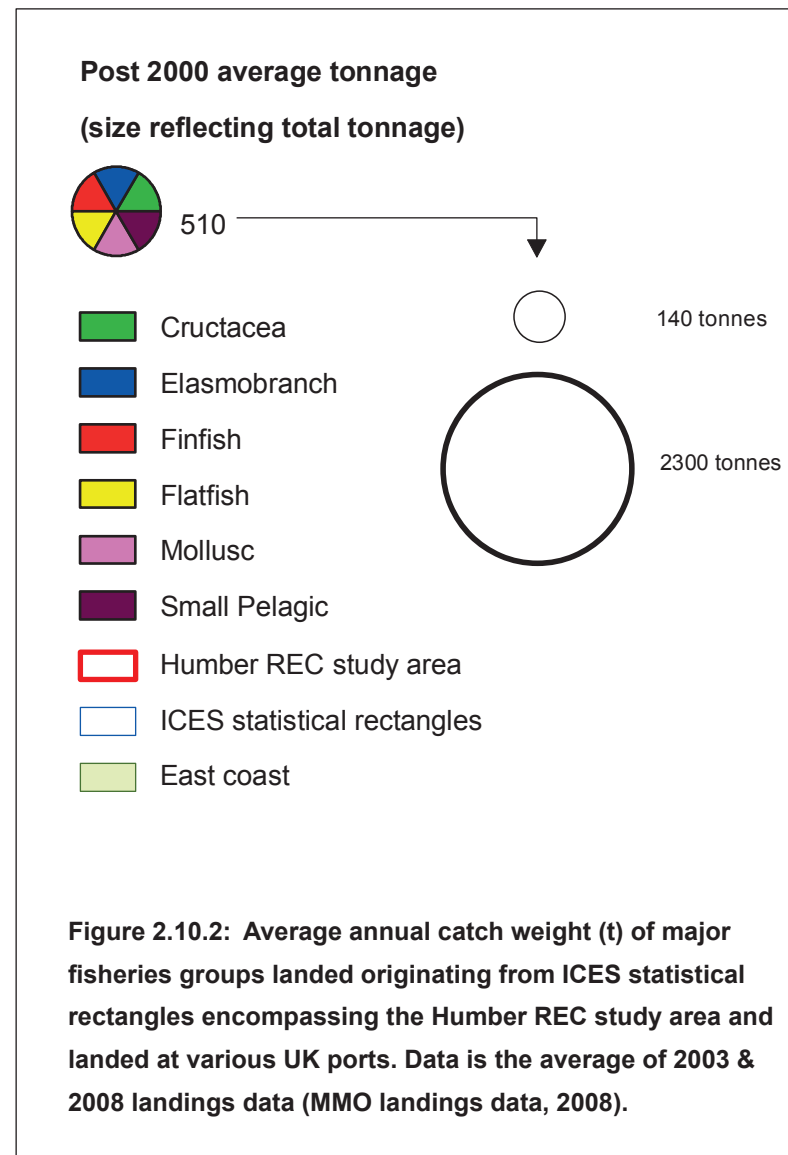
In the North Sea, cod is predominantly fished mostly using demersal trawls; beam trawls, fixed nets and Seine nets are also used (Cotter *et al.* 2004). The North Sea has supported an important winter cod fishery, although this has declined significantly in recent years, with landings declining in from almost 2000 tonnes (t) in 1988 to 89 t in

2008 (Figure 2.10.6). Although spawning stock biomass has increased slightly since an all time low in 2006, research shows that spawning stock biomass is still below biological limits and recruitment since 2000 has been poor (ICES, 2010). For this reason quota levels since 2003 have remained low. The UK North Sea quota for 2011 has been set at 10 455 t which is over 2 500 t less than 2010 (Defra, 2011).

Whiting — *Merlangius merlangus*

The whiting, *Merlangius merlangus* (Figure 2.10.7), is an important commercial fish species belonging to the same family as cod (Gadidae) and as such has been widely studied. It is common on all UK coasts, often found in large shoals. Spawning occurs in open waters between January and July, mostly in early

spring. Temperature seems to be the main trigger for spawning in this species with 5–10°C being optimal. Females produce up to 300 000 eggs per year which, after hatching, remain in the plankton for as long as 12 months. Juvenile whiting are known to be unselective feeders but prey mainly on crustaceans (Shaw *et al.* 2008) with a shift towards fish as they mature (Hostens & Mees 1999; Pinnegar *et al.* 2003; Stafford *et al.* 2007). Juvenile whiting (~3 cm) have often been found sheltering in the tentacles of large jellyfish such as *Cyanea lamarkii* and *Chrysaora isocola*, moving up into the bell to avoid large predators (Lynam & Brierley 2007). As they increase in size the juvenile whiting migrate towards the seabed and are most commonly recorded in coastal areas including estuaries. There is little evidence of any major seasonal

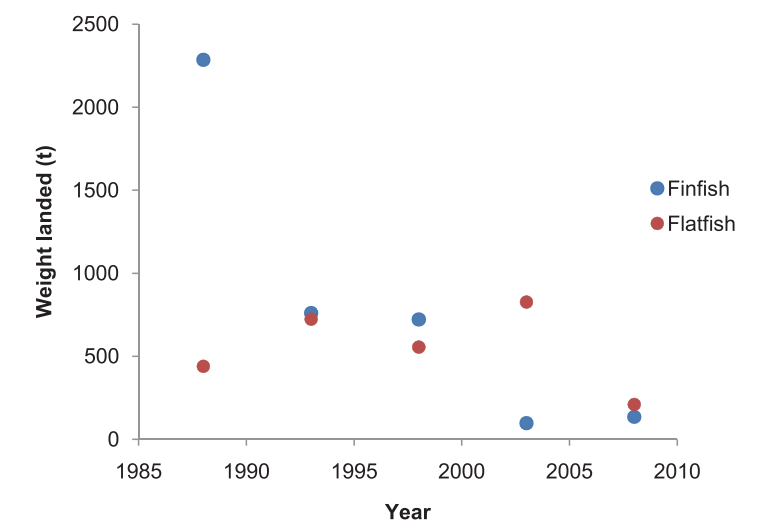


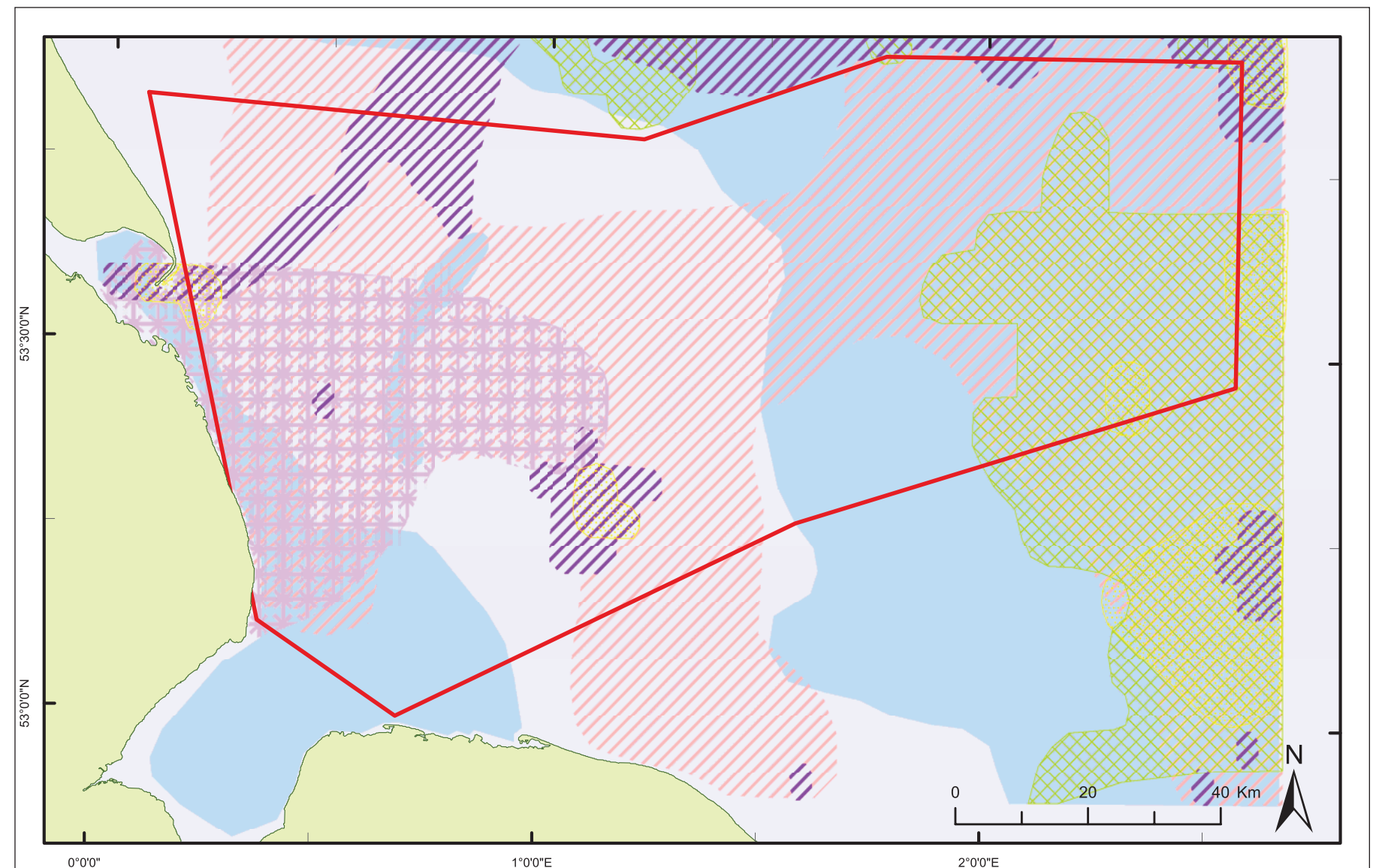
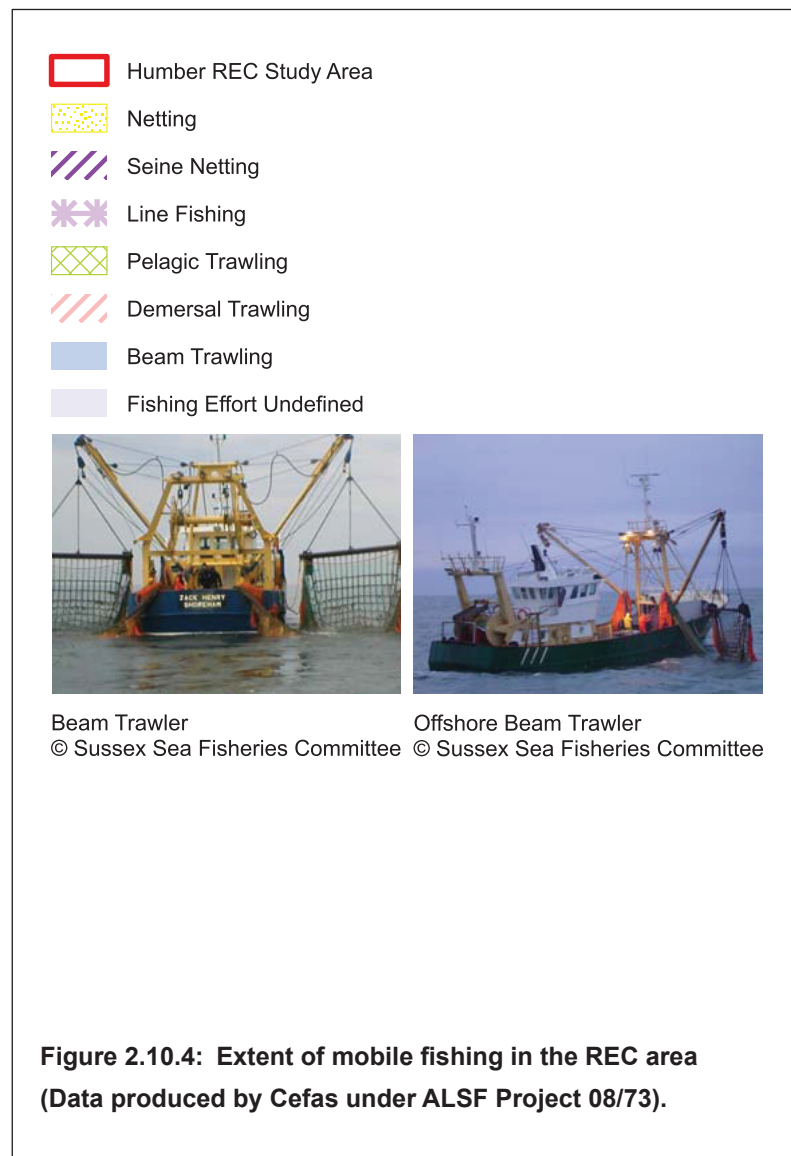
migrations in this species although it has been noted that whiting move into the eastern Channel and southern North Sea during winter and move north between June and October (Carpentier *et al.* 2004).

Whiting represent an important commercial fishery in the Humber REC with 33 t landed in 2008 a significant decrease from 1988 when landings were 193 t, see Table 2.10.1. The main gear used to catch whiting is the rock hopper otter trawl, although small numbers are also caught with gill nets and beam trawls (Cotter *et al.* 2004). In the absence of defined reference points, the state of the stock cannot be evaluated. An analytical assessment

estimates the spawning stock biomass (SSB) in 2008 as the lowest since the beginning of the time-series in 1990. Whiting are heavily preyed upon by large fish, making this species an important component of the food chain. Larger whiting are preyed upon by the grey seal *Phoca vitulina*, and the grey gurnard,

Figure 2.10.3: Weight of total fin fish and flatfish landed (t) from various UK ports originating from ICES statistical rectangles encompassing the Humber REC area for years 1988, 1993, 1998, 2003 & 2008 (MMO landings data, 2008). Sandeels are not included in the finfish data.





Eutrigla gurnardus (Harkonen & Heidejorgensen 1991; Pinnegar & Stafford 2007).

Catches of whiting in the North Sea and eastern English Channel have decreased from 224 000 t in 1980 to 27 000 t in 2008. ICES research has shown that spawning stock biomass in 2009 is slightly higher than 2008, but remains below average. However, 2008 and 2009 recruitment is thought to have been stronger (ICES, 2010). The UK North Sea quota for 2011 has been set at 8 933 t which is increase of 17% from the 2010 quota (Defra, 2011).

Sea Bass — *Dicentrarchus Labrax*

The sea bass, *Dicentrarchus labrax*, is a thick bodied but streamline fish, brilliant silver in colour, with darker fins (Figure 2.10.9). Sea bass are slow growing fish that can reach lengths of up to 1 m although 60 cm for a mature fish is more common. Females lay floating eggs over 4–5 days. Upon hatching fry relocate to estuaries, sheltered bays and creeks. They are found on all UK coasts favouring warm waters in the south. Large numbers of bass can be found in the Thames Estuary and up the west coast as far as Cumbria in the summer, but in autumn they migrate south down to western Cornwall and the English Channel. Bass are targeted

in the summer and autumn south of Sheringham on the north Lincolnshire coast (Walmsley & Pawson 2007).

Sea bass are predatory fish, feeding on small schooling fish such as sand eel, pilchard, herring and crustaceans such as swimming crab. The young predate small crustaceans such as shrimp and small crab (Dipper 2001; Maitland & Herdson 2009; Pinnegar & Stafford 2007). The sea bass fishery is small in the Humber REC area, and is mainly targeted using gill nets but also using demersal trawls and long line fishing (Walmsley & Pawson 2007).

The UK bass fishery developed rapidly between the 1970s and mid 1980s, and involved approximately 3000 fishermen with recorded



Figure 2.10.5: Cod, *Gadus morhua* @ seasurvey.co.uk

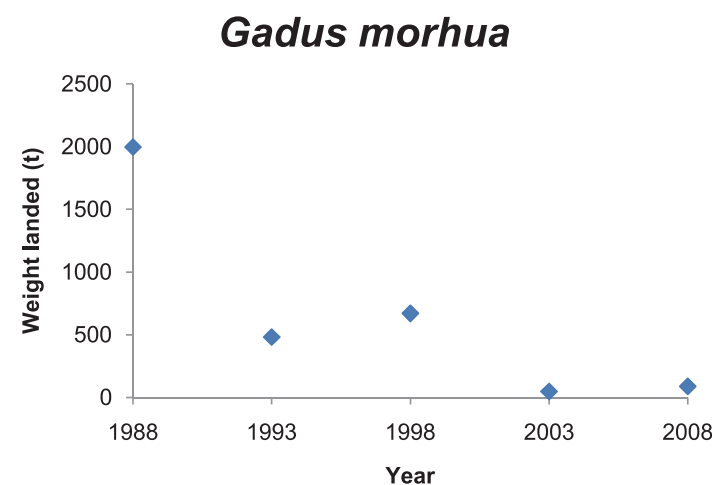


Figure 2.10.6: Cod landings 1988–2008 (MMO data, 2008).

landings of between 3 and 4 million t and significant catches by sport anglers. With evidence of declining stocks fishing restrictions were put in place in 1990. Recruitment of this species increased during the 1990s which may be as a result of the fishing restrictions imposed (Pawson, Kupschus & Pickett 2007; Walmsley & Pawson 2007).

Haddock — *Melanogrammus aeglefinus*

Haddock, *Melanogrammus aeglefinus* is a gadoid fish with 3 dorsal fins, of which the first is pointed, and two anal fins. It also bears a distinctive black thumbprint-like mark on both sides of its body. Haddock may grow to lengths of up to 64 cm, but the largest, recorded off the Icelandic coast, was an impressive 112 cm long. The minimum landing size for haddock is 30 cm.

They breed in the North Sea between February and May, in deep waters (CEFAS & Fisheries Research Services 2001). Fecundity is high with up to 1 million eggs produced. Buoyant eggs float to surface and drift in the ocean currents. The larvae and fry stay as plankton and feed on copepods until mid autumn. Once they reach a size of approximately 5 cm they enter the adult population. Recruitment is variable in this species, and occasionally very successful recruitments are seen such as in 1999 and 2005.



Figure 2.10.7: Whiting, *Merlangius merlangus*
@ seasurvey.co.uk

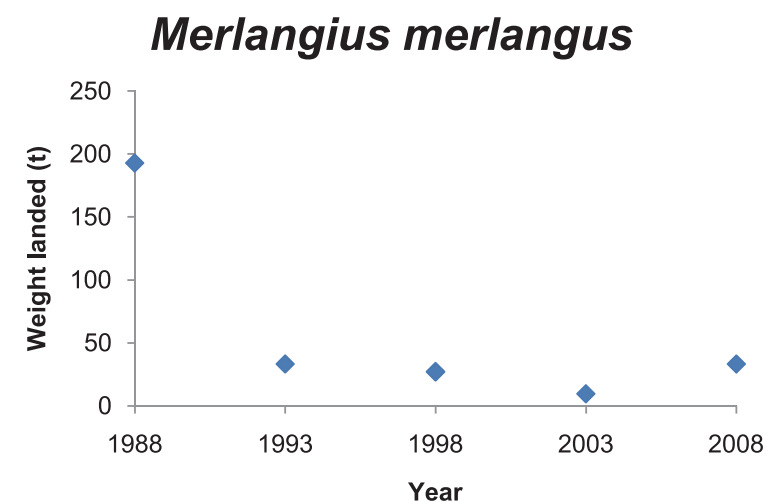


Figure 2.10.8: Whiting landings 1988–2008 (MMO data, 2008).

Haddock are found off all British and Irish coasts, generally at depths greater than 40 m although they can live to depths of 300 m. They often migrate higher in the water column to feed, but usually forage closer to the seabed. Adult haddock eat mainly bottom dwelling organisms such as polychaete worms and molluscs, and occasionally feed on Clupeidae eggs and sand eels (Dipper 2001; Maitland & Herdson 2009).

In the Humber REC area haddock is targeted in mixed fisheries mainly using demersal trawls. Haddock landings from the Humber REC area have fallen in the last 20 years, from 1988 when over 83 t was landed to 2008 where only 2.86 t was landed (Table 2.10.1). ICES research has shown that recruitment is characterized by occasional successful year classes and recent recruitment has been poor. In 2008 the EU agreed to implement a long term precautionary management plan for the haddock (ICES 2010). The UK North Sea quota in 2011 has been set at 22 250 t which is a slight reduction on the 2010 limit (Defra, 2011).

Gurnards — *Triglidae*

Red, grey and tub gurnards, *Aspitrigla cuculus*, *Eutrigla gurnadus* and *Chelidonichthys lucernus* are distinctive bottom-living fish with large armoured heads and distinctive pectoral fins (Figure 2.10.10). The pectoral fins have separate front fin rays which act as feelers.

The tub and red gurnards are similar in appearance although the tub gurnard is generally slightly larger and with distinctive vibrant blue pectoral fin tips. The tub gurnard can grow up to 75 cm but will usually reach sizes between 25 and 50 cm, the red gurnard between 30 and 40 cm. Spawning occurs between March and May and after eggs are released they enter a planktonic phase, a pelagic larval fish phase and when large enough will settle on the seafloor.

The tub gurnard is more common, but both species are believed to be relatively rare off the east coast of England. These gurnards are seen from 5 m down to approximately 200–250 m. They use their three separated pectoral fin rays, which also have chemosensors, to find food. Both species feed heavily on crustaceans (Morenoamich 1994), particularly the brown shrimp (*Crangon crangon*) (Miller & Loates 1997; Dipper 2001). They also eat small bottom-dwelling fish, such as gobies and juvenile cod (Floeter *et al.* 2005).

The grey gurnard, which is less heavily fished in the REC area, is grey to brown in colouration, and will grow to 45 cm, but usually

Common name	Species name	1988 (t)	1993 (t)	1998 (t)	2003 (t)	2008 (t)
Atlantic cod	<i>Gadus morhua</i>	1996	482	670	49	89
Whiting	<i>Merlangius merlangus</i>	193	33	27	10	33
European sea bass	<i>Dicentrarchus labrax</i>	0	0	0	0	4
Haddock	<i>Melanogrammus aeglefinus</i>	83	30	9	21	3
Gurnards	Triglidae	1	3	7	11	3
Anglerfish/Monkfish	Lophiidae	5	15	5	4	1
Red Mullet	<i>Mullus surmuletus</i>	0	0	0	0	1

Table 2.10.1: Annual total live weight (t) of fin fishes landed into various UK ports originating from ICES statistical rectangles encompassing the Humber REC area for years 1988, 1993, 1998, 2003 & 2008 (MMO landings data, 2008).

Common Name	Species Name	1988 (£)	1993 (£)	1998 (£)	2003 (£)	2008 (£)
Atlantic Cod	<i>Gadus morhua</i>	1,681,692	580,937	750,889	70,515	165,097
Common Sole	<i>Solea solea</i>	87,807	389,095	345,911	496,808	98,760
European Seabass	<i>Dicentrarchus labrax</i>	37	128	898	223	26,030
Whiting	<i>Merlangius merlangus</i>	45,244	15,539	12,849	4,140	25,677
Haddock	<i>Melanogrammus aeglefinus</i>	60,034	20,396	6,385	13,338	2,873
Red Mullet	<i>Mullus surmuletus</i>	648	309	1,203	966	2,279
Anglerfish	Lophiidae	7,709	24,669	12,862	6,980	2,145
Gurnards	Triglidae	369	920	1,995	3,435	1,880

Table 2.10.2: Annual total value (£) of fin fish landed into various UK ports originating from ICES statistical rectangles encompassing the Humber REC area for years 1988, 1993, 1998, 2003 & 2008 (MMO landings data, 2008).

is caught at around 30 cm. This gurnard is usually found more inshore than its relatives and is associated with sandy substrates. It eats bottom dwelling crustaceans and small fish, including juvenile cod (Maitland & Herdson 2009).

The red gurnard, as the name suggests is more in red colour than the others. It is recorded as the most important commercial gurnard (MMO data, 2008) although the species are notoriously difficult to tell apart so landings of specific gurnards may not be reliable.

Gurnards are an important prey item for other commercial fish such as cod, angler fish and lesser spotted dog fish (Pinnegar & Stafford

2007). Grey gurnards are caught commonly as by-catch in the North Sea (Pope *et al.* 2000), but are fast swimmers in comparison to other bottom dwellers, therefore speed of trawling has an effect on the catch of these species (Adlerstein & Ehrich 2002). 3 t of Gurnard were landed from the REC area in 2008 which is less than previous years (Table 2.10.1).

Monkfish and White Anglerfish — *Lophius piscatorius* and *Lophius budegassa*

The anglerfish, also known as the monkfish, is a well-camouflaged and curious fish. Anglerfish have a large and broad head with a large



Figure 2.10.9: The European sea bass *Dicentrarchus labrax* @ seasurvey.co.uk

mouth and long curved hinged teeth. It has an intriguing lure on the front of the head, from which gets its name. Once close enough, it will lunge forward and engulf the unsuspecting prey. Once the prey has gone past the hinged teeth, escape is unlikely. Angler fish can reach lengths of up to 2 m but are more usually mature around 1.2 m.

They are common on all coasts around the UK, and usually live below 18 m but can be found shallower. It is associated with a range of substrates, but is usually found on sandy patches around rocks.

Spawning occurs offshore, between spring and summer; a female lays eggs in a single layer of floating gelatinous sheets which can cover an area of 9 m long and 3 m wide. Once hatched, juveniles start life in the water column (Dipper 2001).

MMO landings data do not distinguish between *L. piscatorius* and *L. budegassa* although it is known that the latter species is relatively scarce. Monkfish are a high value fish (in 2008, landings valued at over £2 000 per t from the Humber REC area) usually caught as by-catch by fishermen targeting mixed trawl fisheries. Although there is no accepted analytical assessment of this stock, surveys specifically sampling for monkfish in the North Sea indicate a decline in abundance since 2007 and biomass since 2009. ICES advises a precautionary approach should be adopted. The UK North Sea quota in 2011 has been set at 7 846 t which is almost 1 500 t less than 2010 (Defra, 2011). The anglerfish



Figure 2.10.10: Tub, red and grey gurnard *Aspitrigla cuculus*, *Eutrigla gurnadus* and *Chelidonichthys lucernus* respectively
@ seasurvey.co.uk

is listed in the UK Biodiversity Grouped Species Action Plan for deep-water fish.

Mackerel — *Scomber scombrus*

The mackerel, *Scomber scombrus*, a member of the tuna family Scombridae, is a fast swimming and streamlined, pelagic fish. It is silver in colour, with brilliant iridescent blue green along its back and irregular zebra-like dark lines (Figure 2.10.11). Mackerel can reach a maximum size of approximately 65 cm, however they rarely grow larger than 40 cm. They are found all around the UK in large open water schools. They move inshore in the summer to spawn and then retreat back to large schools in deeper waters over the winter. After spawning mackerel will feed very actively, preying on sprat, sand eels, and herrings as well as filter-feeding on plankton. This type of feeding frenzy makes them susceptible to fishing, in particular long line fishing. During the winter mackerel are not active feeders, spending most of their time on the seabed.

Mackerel are a slow-growing species and as such are particularly vulnerable to commercial fishing pressures (Dipper 2001). Mackerel are an important food source for tuna, sharks, and dolphins, and are also exploited by commercial fisheries. Mackerel are caught using seine nets, pelagic trawls and also on long lines. They have been heavily exploited in the past leading to the collapse of many abundant stocks, particularly those in the North Sea.

Mackerel are caught as by catch, the value in 2008 for the Humber REC area was £883, only 0.47 t were landed for the year.

During the 1960s the purse-seine fishery made extremely large catches of mackerel in the North Sea, subsequently the stock collapsed. North Sea catches in the last five years are approximately 10 000 t. During 2008 egg production decreased by 40%. ICES recommend that there should be no targeted mackerel fishing in the southern North Sea (ICES areas: IVb and IVc)(ICES, 2010).

Hake — *Merluccius merluccius*

Hake, *Merluccius merluccius*, was once classified as a member of the Gadidae family but is now regarded as being distinct enough to be classified as Merlucciidae. It is a slender and long-headed fish with a long posterior dorsal fin. It is silver beneath its lateral line and blue grey above. Hake can grow up to 1.8 m in length but do not usually grow



Figure 2.10.11: Mackerel, *Scomber scombrus*
@ seasurvey.co.uk

above 1 m. Spawning occurs between spring and summer although northern individuals will spawn later at shelf edges (Dipper 2001). Hake is a deep water fish which inhabits the epibenthos at depths between 165 and 550 m. It stays close to the sea bed in the daytime but also forages for fish and squid nocturnally in open water. ICES, has recently assessed the hake stocks to be at full reproductive capacity and are being harvested sustainably. Even so, a precautionary management plan is advised. The hake fishery in the REC area is small.

Ling fish — *Molva molva*

Ling fish, *Molva molva*, are a similar colour to that of cod, brownish-green mottled on toward its dorsum and lighter beneath. They are a deep water species, with a long body that can reach around 1.5 m in length. They breed between early spring and mid-summer and females can produce up to 60 million eggs. Ling are usually found at depths of between 100 and 400 m, occasionally however, large numbers can be found at shallower depths where there is suitable habitat such as rocky grounds and inshore wrecks.

The ling feeds on large crustaceans, cod, whiting and pout. Fish are mainly caught by line by commercial and recreational fishermen. There is a large demand for ling in southern Europe (Maitland & Herdson 2009). Landings in 2008 were low, down from values of over 10 t in the 1990s.

Pouting or Bib — *Trisopterus luscus*

Pouting, *Trisopterus luscus*, is a member of the Gadidae family. They have a diamond shaped body with 3 dorsal and

2 ventral fins (Figure 2.10.12). This species is easily confused with the poor cod. Pouting can reach sizes of 60 cm although usually reach up to 45 cm. Spawning occurs in the spring and occasionally in the summer, usually at depths of 50 and 70 m depth. A female can produce between 20 000 and 1.3 million eggs (Alonso-Fernandez *et al.* 2008). Pouting is a shoaling species, common all around the UK coasts in areas of mixed rock and sand. It can live to a depth of 300 m. It feeds on molluscs and crustaceans, especially shrimp although older fish will actively predate squid and fish. Landings of pouting by-catch, which is usually used as fish meal, in the REC area are small (0.26 t worth £144 in 2008).



Figure 2.10.12: Pouting, *Trisopterus luscus* @ seasurvey.co.uk

Pollack & Saithe — *Pollachius pollachius* & *Pollachius virens*

Pollack and saithe (or coley) are similar looking species from the Gadidae family and are often reported as the same species. Most have a streamlined silvery appearance although occasionally older fish are dark in colour. There are subtle differences between the two species. Pollack have a curved and dark lateral line, the saithe's is straight and light coloured. Also the bottom jaw protrudes in the pollack but not in the saithe. Generally, saithe are larger, growing up to 80 cm compared to the pollock's 50 cm.

Pollack and saithe spawn in late winter to early spring, at depths between 100 and 200 m. Eggs and larvae are planktonic and float towards inshore waters and successful juveniles who survive the 'drift' inhabit inshore waters and feed on crustaceans. Adults live more offshore and feed on small pelagic and demersal fish such as herring and sand eels.

Both species are common off all British coasts. They are found swimming through kelp forests and around rocks and wrecks, but most often are found in the open sea. Juveniles inhabit inshore areas amongst rocks and seaweed. Pollack are common in estuaries and saithe can be found in rock pools at low tide. With the exception of 1993, where relatively high landings (almost 9t) were recorded pollack is rarely caught from the REC area.

2.10.2 Flatfish

Sole and plaice are the main flatfish fishies within the Humber REC area, with a similar value to that of finfish. They are generally fished by beam trawlers.

Plaice — *Pleuronectes platessa*

Plaice, *Pleuronectes platessa*, is probably the easiest flatfish to recognise with its distinct orange to red spots (Figure 2.10.13). Continued pressure from fishing means that larger specimens are rare, but individuals up to 50 cm are still recorded fairly frequently (Miller & Loates 1997; Dipper 2001). They spawn between January and April, with each female producing up to half a million eggs. In the UK this occurs in well-defined areas at depths between 20 and 40 m. Most plaice from the southern North Sea congregate on the Flemish Bight to spawn, between the Thames Estuary and the Dutch and Belgian coasts (Dipper 2001). Plaice reach their peak densities in May within spawning grounds. In June and July older fish individuals migrate, and large numbers of juveniles remain in the intertidal zone until the autumn (Kuipers 1977). The larval fish then spend a further 4–6 weeks in the plankton before finally settling on sandy areas which act as nursery grounds.

Like other flatfish, plaice feed most intensively in spring (Kuipers 1977) on bottom dwelling animals, although a preference for shellfish such as cockles and razor clams has been reported (Amezcu, Nash & Veale 2003). Shellfish are of greater importance in the diet of adult plaice as they are able to crush the shells with their strong pharyngeal teeth (Dipper 2001).

Plaice are found on all UK coasts, typically on sandy substrata, but also on gravel and mud and are frequently observed on sand patches in rocky areas. They are currently, and historically, the most important commercial flatfish in the Humber REC area (Table 2.10.3). In 2008 the weight of total landings from this area was 173 t. Plaice

recruitment has been at a long-term average strength since 2005 although a slightly weaker recruitment was seen in 2008. ICES has declared that the stock is well within the precautionary boundaries advised and declared the 2011 plaice quota as a precautionary approach (ICES, 2010). The 2011 UK North Sea quota for plaice is 19 599 t which is over 2 500 t more than the 2010 quota.

Recruitment has been at a long-term average strength since 2005 although a slightly weaker recruitment was seen in 2008. The European commission has not agreed a management specifically for plaice but has implemented a management plan to reduce fishing mortality for flat fish in the North Sea, agreed in June 2007 (ICES 2009a).

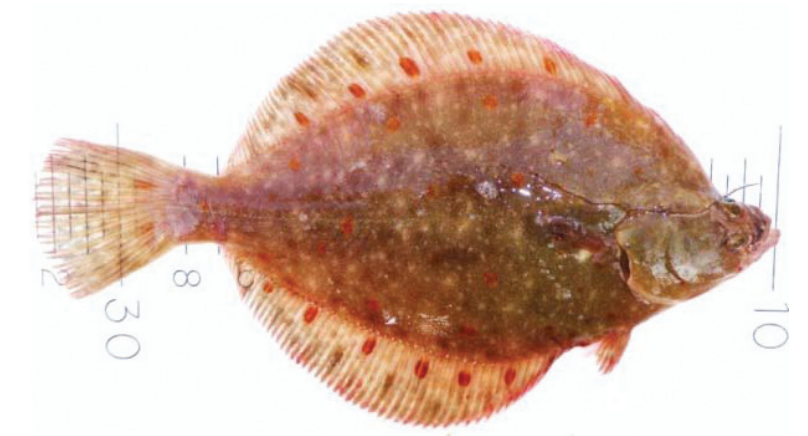


Figure 2.10.13: The European plaice, *Pleuronectes platessa* @ seasurvey.co.uk

Dover Sole — *Solea solea*

Dover sole, *Solea solea*, is a distinctive flatfish with a rounded head with characteristic filaments, and a low slung semi-circular mouth (2.10.14). The maximum size is 60 cm, but due to fishing pressure they usually only reach 40 cm.

In the North Sea spawning commences in March when the water temperature reaches approximately 7°C, peaks in April and fish continue to spawn until late June. Spawning occurs inshore particularly in estuaries including the Wash and the Humber (Burt, 2008). Females release up to 500 000 eggs which drift in the plankton, usually into high productivity shallow sandy nursery grounds close to the spawning area, which provide a good feeding ground for the juveniles (Dipper 2001). Sole inhabit nursery

grounds for up to two years before migrating offshore (Rijnsdorp *et al.* 1991). The Wash and Humber area is of great importance to the recruitment of Dover sole stock.

Sole is widely distributed around the UK and Ireland, predominantly on sand and muddy substrata. Sole from the REC area are found in shallow water in the summer, migrating to warmer, deeper waters in winter. During migrations sole have been shown to travel distances of up to 763 km (Burt & Millner 2008). Like many other demersal species, sole spend the daytime buried in sand and are most active at dawn and dusk (Dipper 2001). They have been reported as feeding on small bottom-living animals: mostly polychaetes, molluscs and crustaceans (Miller & Loates 1997; Darnaude, Harmelin-Vivien & Salen-Picard 2001).



Figure 2.10.14: The Dover sole, *Solea solea* @ seasurvey.co.uk

Yearly landings of Dover sole from the Humber REC area are variable (Table 2.10.3). A survey concluded that the general consensus of southern North Sea fishermen is that sole increased in numbers during 2009. Sole is targeted by static and drift netters, as well as by beam and otter trawlers (Cotter *et al.* 2004) but are mainly fished in a mixed beam trawl fishery using an 80 mm mesh. For the last decade the spawning stock has fluctuated around precautionary limits set by ICES and fishing mortality has been seen to decline since 1995. ICES has evaluated the North Sea Sole EU management plan as precautionary (ICES, 2010). However, it has been reported that undersized sole are discarded and have shown to have a survival rate of as little as 10% (Van Beek, Van Leeuwen & Rijnsdorp 1990). The 2011 UK Sole TAC for the North Sea is 602 t, which is the same weight as 2010 (Defra, 2011).

Dab — *Limanda limanda*

The dab, *Limanda limanda*, has a characteristic lateral line with a very obvious arch over the pectoral fin (Figure 2.10.15). They are brown in colour, occasionally with small orange spots but not to the same extent as plaice. Individuals can grow up to 40 cm in length, but usually only reach 25 cm. They usually live on the sea floor between depths of 20 and 40 m.



Figure 2.10.15: The common dab, *Limanda limanda* @ seasurvey.co.uk

Females produce approximately 150 000 eggs which float. Juveniles generally settle in inshore waters of less than 1 m in depth and the adults migrate to deeper waters between May and September (Dipper 2001).

Dab feed nocturnally on polychaetes, brittle stars, molluscs and occasionally sand eels. Dab are known to be prey of both cod, and to a lesser extent, the grey gurnard (Pinnegar & Stafford 2007). They are very common flatfish, especially in the North Sea where almost 10 t were landed in 2008 (Table 2.10.3).

Turbot — *Psetta maxima*

The turbot, *Psetta maxima*, is almost completely round, scale-less but with scattered tubercles on the dorsal surface. It is one of the largest flatfish, sometimes reaching a maximum length of 1 m, though more usually maximum size is between 55 and 80 cm.

Females spawn in large quantities, up to 10–15 million eggs (Maitland & Herdson 2009; Moen & Svensen 2004) from May

to September on gravel bottoms at depths of <40 m. After an extended period in the plankton (4–6 months) the young drift into shallow waters to settle and develop (Dipper 2001).

Adults live at depths of 10–80 m on sand or gravel, and are also known to inhabit muddy areas and mixed rocky substrata. Turbot actively predate fish which they can catch easily with their large extendable mouth, preferred prey includes; sprat, herring, whiting and other gadoids (Dipper 2001).

Turbot are most common in the south of the UK, although they are found in lower abundances on all other UK coasts. It is a very valuable commercial fish, with most of the catch coming from by-catch from beam trawling, netting and long lines (Cotter *et al.* 2004; Dipper 2001). Landings in the Humber REC area in 2008 reached 6.6 t (Table 2.10.3). This species has also been successfully cultivated in captivity and farmed turbot are now available from the UK. Whilst much research has been compiled into the life cycle and biology there is lack of research on wild stocks.

Brill — *Scophthalmus rhombus*

Brill is a large camouflaged flatfish, able to change colour to match the background (Figure 2.10.16). They can reach a size of 75 cm, but typically only reach 50 cm. Spawning occurs in spring and summer in water <20 m where the young tend to stay for up to a year. The juvenile fish stay in the water column until they adopt a typical flat fish shape, at which point become negatively buoyant and settle on the seafloor.

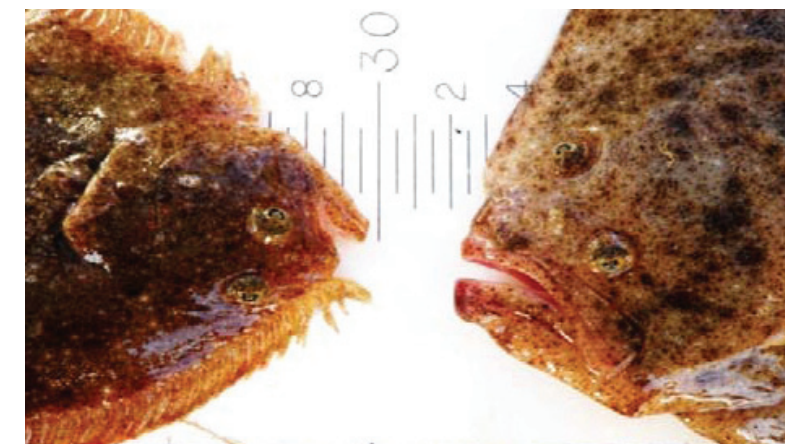


Figure 2.10.16: Brill (left) and turbot (right) *Scophthalmus rhombus* and *Psetta maxima* respectively @ seasurvey.co.uk

Adults are found on all UK coasts, but are most common in the south, on sandy bottoms, but also on gravel and mud. They feed mostly on juvenile whiting, sand eel, squid, gobies and crustaceans (Dipper, 2001).

Brill are fished commercially by beam trawlers and are also caught in fixed nets (Cotter *et al.* 2004). Landings of both brill and turbot have declined in recent years (Tables 2.10.3 and 2.10.4). Brill is a valuable fish, it slightly less value per tonne than turbot from the REC area during 2008 (£5350 per tonne). Stocks are managed using a precautionary TAC for both turbot and brill.

Lemon Sole — *Microstomus kitt*

The lemon sole, *Microstomus kitt*, is one of the more attractive flat fishes found in the UK with a multi-coloured mottled appearance (Figure 2.10.17). It can reach lengths of up to 70 cm, but usually grows to around 40 cm in length. They are found on all UK coasts but are abundant only in certain areas, showing a preference for firm sand and gravel (Miller & Loates 1997; Dipper 2001). They live at depths between 20 and 200 m.

Unlike plaice and sole, lemon sole do not have well defined spawning grounds, but it is thought that juvenile fish (below 15 cm) have a preference for rocky areas between 50–100 m deep (Jennings, Howlett & Flatman 1993).

Lemon sole have a much smaller mouth than many of their flatfish relatives and with a lack of powerful crushing teeth are limited in their diet. They therefore tend to feed mainly on soft bodied



Figure 2.10.17: The lemon sole *Microstomus kitt*
@ seasurvey.co.uk

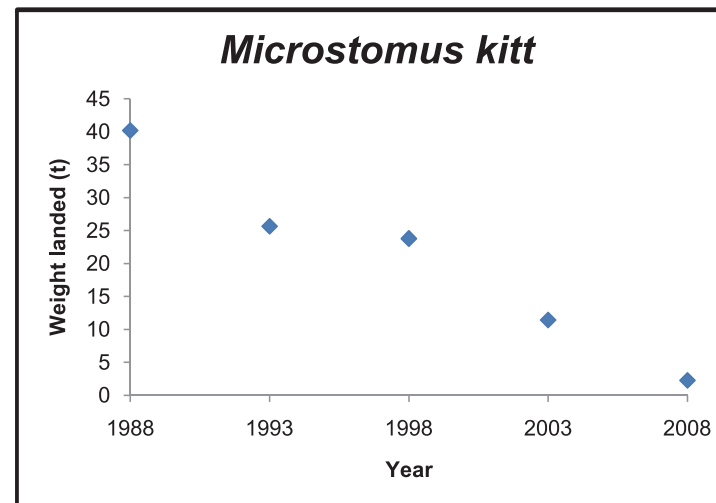


Figure 2.10.18: Lemon sole landings 1988–2008
(MMO data, 2008).

polychaetes and bivalve siphons, cutting the tops off with their sharp cutting teeth (Dipper 2001; Amezcua *et al.* 2003).

Landings from the Humber REC area have steadily declined over the last 20 years, this may be clearly seen in Figure 2.10.18. There is a lack of data on stocks in the North Sea as ICES has not assessed this stock. The EC has set a precautionary TAC (which includes witch flounder).

Flounder — *Platichthys flesus*

Flounder, *Platichthys flesus*, is of a similar appearance to plaice, although there are no obvious orange markings. There are also tubercles present along the base of the fishes' dorsal and ventral fins and the tail is square cut. The underside of the fish is a pale yellowy green colour with occasional markings. They can reach a maximum length of 50 cm, but rarely grow larger than 30 cm. They occasionally interbreed with plaice.

Breeding occurs during the spring. Until the juvenile flounder reaches approximately 1.5 cm it is positively buoyant and surface-living (Dipper 2001; Maitland & Herdson 2009). Adults live from just below the shoreline to approximately 50 m deep and can be very abundant in estuarine environments and also fresh water connected to the sea. They inhabit muddy and sandy bottoms,

where adults feed selectively on brown shrimp but also feed on molluscs such as cockles and polychaetes.

This fish has a low commercial value, and is not an important fishery in the area but is important for angling.

Atlantic Halibut — *Hippoglossus hippoglossus*

Atlantic halibut, *Hippoglossus hippoglossus*, is a very large, sometimes dark, green-brown flatfish that can reach lengths of 2.5 m. They have a very large mouth with both jaws bearing teeth and a lateral line with an obvious arch over the pectoral fin. Spawning occurs in deep waters during early spring, the eggs are planktonic for up to 2 weeks, and once the juveniles reaches a size of 4 cm they settle and dwell on the seabed. It takes almost 13 years for a halibut to reach sexual maturity; males stay in deep waters whereas females and juveniles are common on offshore banks (Maitland & Herdson 2009). Juveniles feed on shrimps, squid and sand eels, adults on many commercial fish such as small rays, cod, herring and haddock. The halibut is a deep water fish and is found in waters between 50 m and 2 000 m depth. Unusually for a flat fish, it occasionally hunts mid-water. This species is caught as by-catch on the east coast. Although only 0.64 t of halibut were landed in 2008 (Table 2.10.3), it is still an important commercial flatfish because it is a high value fish (in 2008 its value reached almost £6 000 per tonne — MMO, 2008). This species is on the IUCN red data list as endangered. The EU quota set for the UK was 330 t for 2009.

2.10.3 Small Fish

Small fish species, such as sprat and herring, are often variable in terms of recruitment and stocks can be very unpredictable making them particularly difficult to manage. Herring and sprat prices are variable which correlates with fishing effort. Historically, there have been good herring and sprat fisheries in the Wash and approaches. In recent decades however, the market has been poor as there is no longer such high demand for these species. Combinations of variable populations and a market driven industry can vary effort which is put into the fishery.

Sandeels — *Ammodytidae*

Sandeels are small eel like fish with a long thin body and a pointed jaw (Figure 2.10.19). There are three main species found in the

UK, *Ammodytes tobianus*, *Ammodytes marinus* and *Hyperoplus lanceolatus* which are relatively difficult to tell apart and are not normally separated in fisheries data. Sandeels usually lay their eggs in spring and summer in the sand over which they live. Each female can lay between 4 000 and 20 000 eggs. These hatch a few weeks later, and the tiny fish move out of the sand and into the water column. Sandeels feed on small planktonic animals living in the water column as well as worms, small crustaceans and fish. They are known to prefer medium to coarse sand and have been shown to avoid areas with high levels of coarse gravel, fine gravel, and silts (Holland *et al.* 2005). Availability of suitable habitat is a key constraint to the distribution of sand eels. There are sandy areas within the Humber REC boundary which have been identified as both a spawning and nursery ground for the sand eel (Coull *et al.* 1998).



Figure 2.10.19: The greater sandeel, *Hyperoplus lanceolatus* (top) and the lesser sandeel *Ammodytes tobianus* (bottom) @ seasurvey.co.uk

The sandeel fishery is one of the largest industrial fisheries in the UK; sandeels are mainly caught for fish meal. They also constitute important prey for many large marine predators including grey seal, harbour seal, porpoise and many seabirds, especially puffins. They are also a very important prey source for larger fish, such as cod, herring, salmon, bass and mackerel (Dipper, 2001). With so many predators dependent on sandeels, the level of exploitation has raised concerns regarding the impact on marine food webs (Holland *et al.* 2005).

There have been indications that the eggs of the copepod *Calanus finmarchicus* support sand eel larvae. Population shifts caused by

Common Name	Species Name	1988 (t)	1993 (t)	1998 (t)	2003 (t)	2008 (t)
European plaice	<i>Pleuronectes platessa</i>	359	564	415	677	173
Common sole	<i>Solea solea</i>	22	81	52	78	13
Common dab	<i>Limanda limanda</i>	6	14	42	37	10
Turbot	<i>Psetta maxima</i>	6	20	8	12	7
Brill	<i>Scophthalmus rhombus</i>	5	19	13	10	3
Lemon sole	<i>Microstomus kitt</i>	40	26	24	11	2
Atlantic halibut	<i>Hippoglossus hippoglossus</i>	0	0	0	0	1

Table 2.10.3: Annual total live weight (t) of total flatfishes landed into various UK ports originating from ICES statistical rectangles encompassing the Humber REC area for years 1988, 1993, 1998, 2003 & 2008 (MMO landings data, 2008).

Common Name	Species Name	1988 (£)	1993 (£)	1998 (£)	2003 (£)	2008 (£)
European plaice	<i>Pleuronectes platessa</i>	281 267	656 170	530 595	997 862	239 630
Common Sole	<i>Solea solea</i>	87 807	389 095	345 911	496 808	98 760
Turbot	<i>Psetta maxima</i>	27 533	105 388	58 599	82 688	49 418
Brill	<i>Scophthalmus rhombus</i>	18 393	60 612	61 122	45 850	15 981
Common dab	<i>Limanda limanda</i>	2 628	7 390	26 110	21 011	7 436
Lemon sole	<i>Microstomus kitt</i>	61 169	54 308	52 829	27 405	4 146
Atlantic halibut	<i>Hippoglossus hippoglossus</i>	322	587	1 448	1 818	3 753

Table 2.10.4: Annual total value (£) of flatfishes landed into various UK ports originating from ICES statistical rectangles encompassing the Humber REC area for years 1988, 1993, 1998, 2003 & 2008 (MMO landings data, 2008).

climate change in this species may lead to less prey availability in early life stages of the lesser sand eels (van Deurs *et al.* 2009). Like other short lived species, sand eel stocks can be highly variable as recruitment is dependent on many factors. High natural mortality also makes it difficult to assess stocks of this species.

ICES has advised that those fishing grounds which are known to be commercially depleted should be closed to fishing in 2011; while those which are not depleted should be allowed.

In 2009, ICES estimations of North Sea spawning stock biomass has indicated that the North Sea sand eel stock had reduced reproductive capacity (ICES, 2009). However, more recent research has shown that the southern North Sea 2011 spawning stock biomass and 2009 recruitment abundance are above

average (ICES, 2010). The 2011 UK quota has been set at 4 995 t which is an increase of over 1 000 t from the 2010 quota (Defra, 2011).

Sprat — *Sprattus sprattus*

The sprat, *Sprattus sprattus*, is a smaller relative of the herring and an important component of the diet of larger fish. They form coastal and estuarine shoals in winter before spawning offshore between May and August in the North Sea. The eggs are pelagic and after metamorphosis the juveniles migrate to inshore nurseries, which exist within the Humber REC boundary and most of the eastern English coastline (Coull *et al.* 1998). The sprat fishery in the North Sea is dominated by young fish and the stock size is driven mainly by the success of recruitment (ICES 2010).

The sprat fishery is an example of an industrial fishery; the fish are caught not for food but are used more in fish meal and as bait. Sprat is very abundant in the shallow areas of the North Sea (CEFAS & Fisheries Research Services 2001). There is a small sprat fishery within the Wash which is limited by market demand. Sprat and small herring are very similar and undoubtedly confused when recording the landings. A large sprat landing was recorded in 2008 of almost 200 t (MMO data, 2008) in the eastern section of the Humber REC area.

Herring — *Clupea harengus*

The herring, *Clupea harengus*, is a pelagic fish, silvery in colour with shimmering deep blue shading along its back (Figure 2.10.20). Herring are abundant and widely distributed around the UK, with geographically distinct breeding stocks or races, the majority of which are migratory. The times and places of spawning vary according to the stock but all have distinct grounds. Stocks that spawn in spring tend to use inshore spawning grounds, whilst autumn and winter spawners tend to move offshore using the edges of ocean banks. In all cases large numbers of eggs (up to 50 000) are laid by the females near the seafloor which sink and stick to gravel, shell and stones to form a dense mat. Eggs are sometimes laid in a series of spawning episodes, several weeks apart (Dempsey & Bamber 1983). Juvenile fish aggregate in shoals and migrate into estuaries and other shallow waters where they remain for between six months and a year (Dipper 2001). The Humber REC area does overlap with identified herring spawning grounds and since the area contains a significant gravel component it is possible that there are important spawning areas within this boundary. Herring nursery grounds are particularly vulnerable to physical disturbance by trawling and dredging (ICES 2010).

The major commercial population of herring in the North Sea are autumn spawners, grouped into three geographical blocks; the Buchan stock centred off north-east Scotland, the Banks stock, which spawns on and around the Dogger Bank and off the Northumberland and Yorkshire coasts, and the Downes stock, which spawns in the eastern English Channel (MESL 2003).

As herring is a pelagic species, and local commercial landings are low, it is unlikely that the Humber region is significant as far as

the movement and potential capture of adult stocks is concerned. However there is a significant herring fishery throughout the North Sea.



Figure 2.10.20: The herring *Clupea harengus* @ seasurvey.co.uk

The North Sea herring fishery is for human consumption and bycatch from industrial fisheries, using either beam or pelagic trawls (ICES 2010; Cotter *et al.* 2004). ICES research suggests that every year since 2002 recruitment has been at its lowest for 40 years. The EU has agreed a specific management plan for herring, ICES has concluded that a precautionary approach is required (ICES, 2010). The 2011 UK North Sea quota was set at just over 30 000 t (Defra, 2011).

2.10.4 Shellfish

Shellfish is a term used in fisheries science for commercial marine invertebrate species of crustaceans and molluscs. This is despite the fact that they may have very different life histories, dispersal techniques and habitat requirements. So here we describe crab, lobster, shrimp, cockles and mussels. The areas where they are fished are shown in Figure 2.10.21. The landings, both in terms of the tonnage and price, for some of the crustacean species are found in Tables 2.10.5 and 2.10.6.

Crustacea

Crustacean fisheries are very important in and around the Humber REC area, especially at ports where traditionally there have been large whitefish fisheries. Currently crustacean fisheries are managed on a national and local level through Defra licensing and North Eastern and Eastern Sea Fishery Joint Committee by-laws. Over recent years effort has increased as fishermen have switched from demersal trawling to potting which provides the majority of the

income for many fishers in the area, especially where landings of finfish have fallen. Some fishing boats set up to 2000 pots each off the Yorkshire coast. July to September are the most active months due to favourable weather conditions and increased activity of lobsters (Walmsley & Pawson 2007).

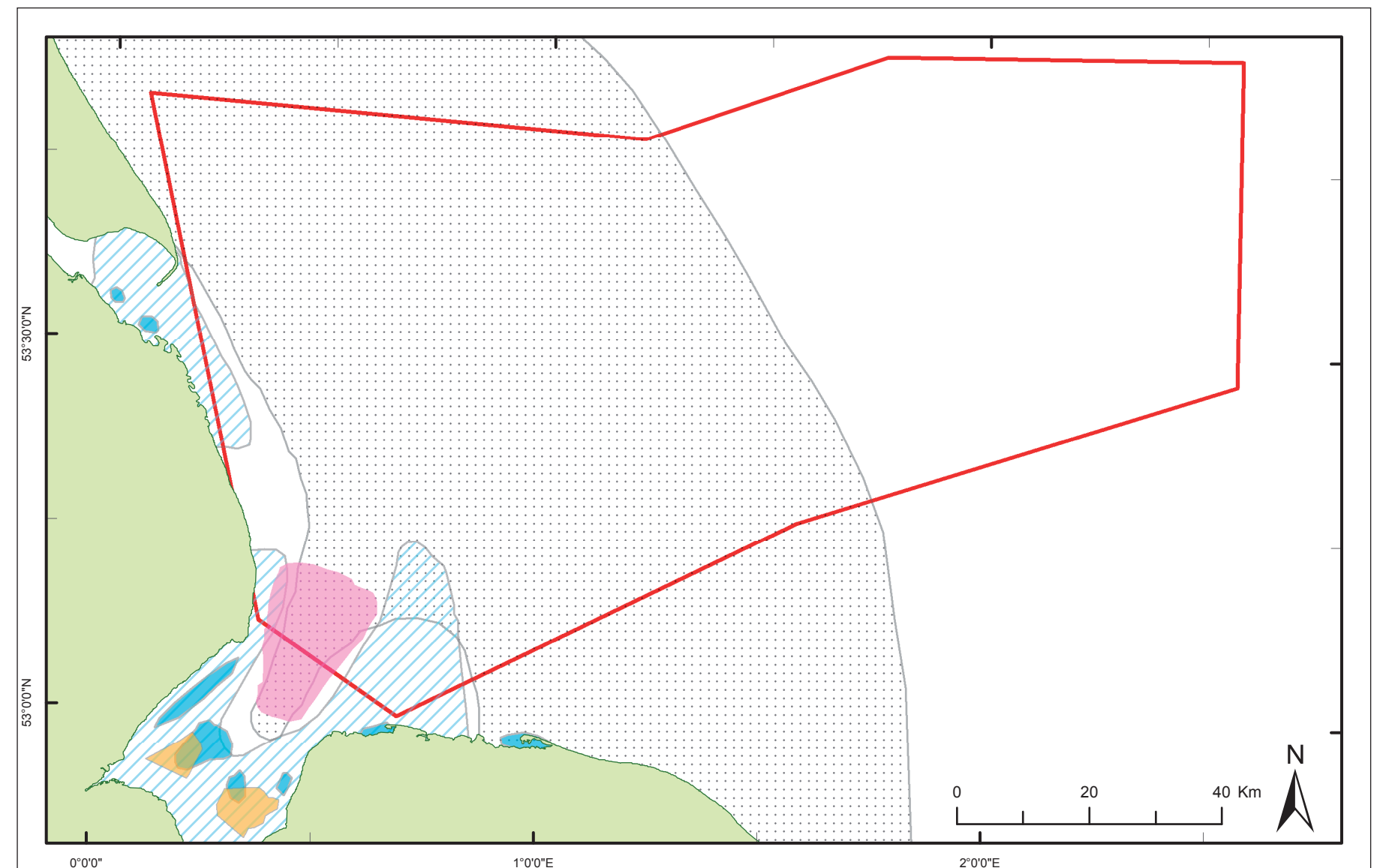
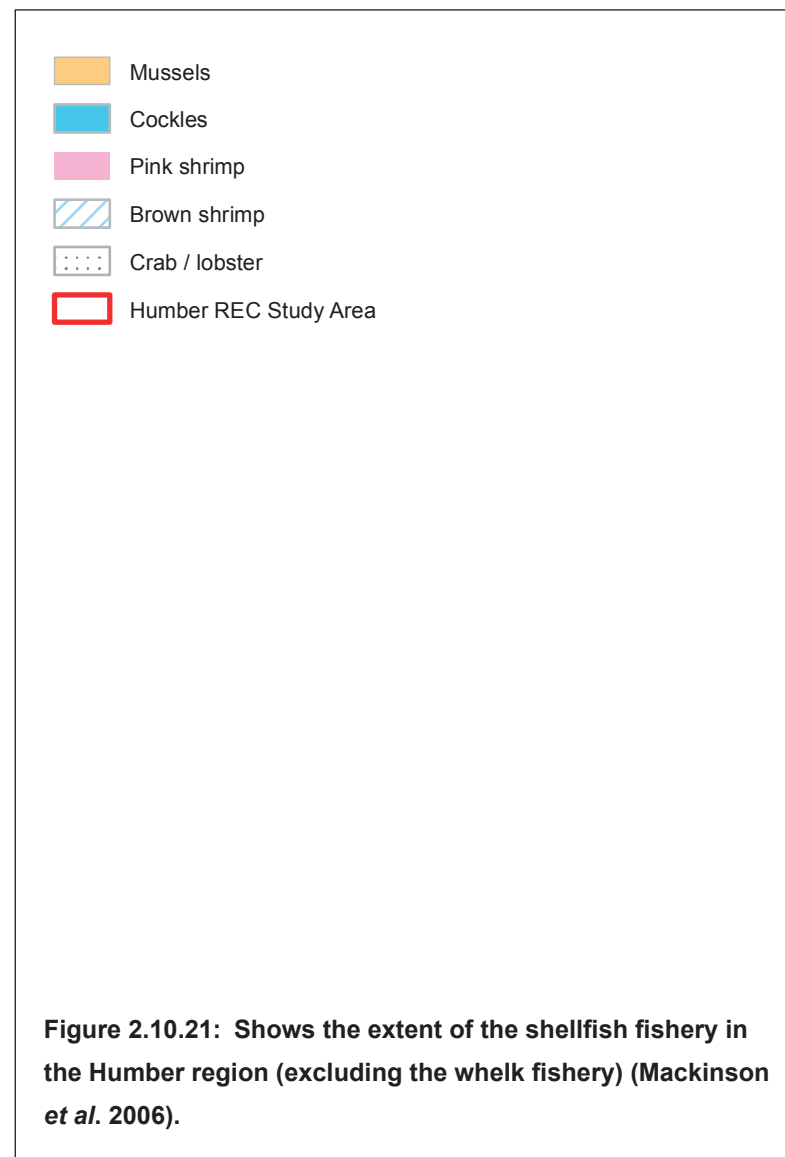
Edible Crab — *Cancer pagurus*

The edible or brown crab, *Cancer pagurus*, is a robust crab of a reddish-brown colour, with an oval carapace and black tipped claws (Figure 2.10.22). Mature adults may have a maximum carapace width of about 250 mm and can weigh up to 3 kg. This crab is an omnivorous feeder but shows a preference for bivalve molluscs and polychaetes. The large powerful claws are well adapted to crush shelled molluscs.

Crabs mate by copulation in the spring and summer and the females are gravid (carrying eggs under the abdomen) for 6–9 months. To keep the eggs healthy, the female crab continually 'waves' water over the eggs with the pleopods (tiny leg like appendages on the abdomen). During this time the females remain in pits dug in the sediment or under rocks and do not feed. Because females are unlikely to be caught in baited pots during this time fishing pressure does not directly affect the larval supply (Howard 1982). In the North Sea, gravid females migrate offshore to release larvae and then move back inshore to feed. Upon hatching the larvae remain in the water column for between 60 and 90 days before settling. After settlement, juveniles move into shallow waters and are mostly found on rocky shores. When they reach maturity they move back into deeper waters.

The edible or brown crab is a major fishery targeted by a number of the fisheries working within the Humber region (MESL 2003) and the east coast contributing a significant amount of weight to all fisheries landings in 2008 (Table 2.10.5). The fishery is located off the Lincolnshire coast, at Race Bank, Dudgeon Shoal and Triton Knoll, between spring and autumn. Further north off the north Lincolnshire coast and Yorkshire coast weather conditions have the most affect on the fishing effort. Smaller boats bring in pots during the winter months for fear of equipment damage.

There is some debate about the migrations of edible crab in the Humber region. Historically, tagging studies have indicated that the Race Bank and north Norfolk fishery depended on the north



easterly migration of brooding females from that area, to the Yorkshire coast. More recent work however suggests that this may be a discrete and self maintaining population (Eaton *et al.* 2003).

The North Eastern Sea Fisheries Joint Committee (NESFJC) have shown that mean carapace widths have increased since increased minimum landing sizes were introduced (from 125 mm–130 mm) in 2000. This trend has led to the conclusion that the crab fishery in the district is sustainable. However, increased effort has been seen which will undoubtedly put pressure on the fishery and stocks will need to be monitored closely. Mean carapace size in the southern section of the NESFJC's jurisdiction (which ends a

few miles south of Cleethorpes) is significantly smaller than that of the north, but is stable and an increase was seen in 2004 (NESFC 2004).

Lobster — *Homarus gammarus*

The common lobster, *Homarus gammarus*, (Figure 2.10.23) is found from the intertidal zone down to depths of 200 m on all UK coasts. Lobsters are nocturnal feeders, feeding on carrion and bivalve and gastropod molluscs using their strong crushing claw.

Mating occurs in the summer, when females are soft, post moulting, although fertilisation is not always immediate and

females can retain sperm for up to a year. The eggs are moved to the tail and attach to the lower hairs (setae) of the pleopods (Jessop, Wood & Harwood 2008). Larvae remain in the plankton for approximately 3 weeks before settling (Moen & Svensen 2004).

Lobsters are not known to make structured migrations, but they are known to move long distances across featureless seabed to find suitable shelter and to re-colonise fished-out reefs (Mercer *et al.* 2001). Suitable habitats are believed to be rocky or large cobbles (Bannister & Howard 2001) and include small crevices for protection from predators.

Common name	Species Name	1988 (t)	1993 (t)	1998 (t)	2003 (t)	2008 (t)
Edible crab	<i>Cancer pagurus</i>	100	1059	1943	4390	2035
Common shrimp	<i>Crangon crangon</i>	661	943	644	545	809
European lobster	<i>Homarus gammarus</i>	24	31	169	168	440
Velvet swimming crab	<i>Necora puber</i>	0	0	0	149	163
Norway lobster	<i>Nephrops norvegicus</i>	0	0	10	28	38
Pink shrimp	<i>Pandalus spp.</i>	376	31	55	27	13

Table 2.10.5: Annual total live weight (t) of crustaceans landed into various UK ports originating from ICES statistical rectangles encompassing the Humber REC area for years 1988, 1993, 1998, 2003 & 2008 (MMO landings data, 2008).

Common Name	Species Name	1988 (£)	1993 (£)	1998 (£)	2003 (£)	2008 (£)
European lobster	<i>Homarus gammarus</i>	163 807	235 882	1 419 458	1 608 065	4 809 817
Edible crab	<i>Cancer pagurus</i>	77 779	800 806	1 660 135	3 861 852	2 713 808
Common shrimp	<i>Crangon crangon</i>	886 244	1 238 804	982 509	885 963	2 436 841
Velvet swimming crab	<i>Necora puber</i>	0	0	0	175 388	254 796
Norway lobster	<i>Nephrops norvegicus</i>	156	9	23 713	123 180	88 224
Pink shrimp	<i>Pandalus spp.</i>	304 059	26 639	48 841	29 274	14 759

Table 2.10.6: Annual total value (£) for crustaceans landed into various UK ports originating from ICES statistical rectangles encompassing the Humber REC area for years 1988, 1993, 1998, 2003 & 2008 (MMO landings data, 2008).

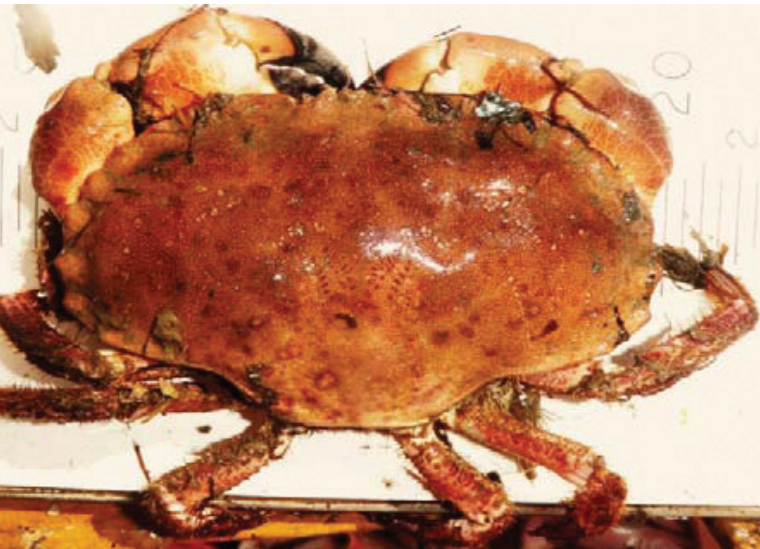


Figure 2.10.22: The edible crab, *Cancer Pagurus*
@ seasurvey.co.uk

Lobster is the most important commercial species within the Humber REC area. Landings of lobster have increased significantly over the last 20 years (Figure 2.10.24). It is targeted using pots, but is also caught and landed as by-catch by demersal trawlers. Lobsters are potted in an area up to 40 miles off the Yorkshire and north Lincolnshire coast. The ESFJC have found lobsters tend to be smaller in inshore grounds than those found in the Wash and offshore. Lobsters caught between August and October tend to be larger than those caught earlier in the season. This could be as a result of either migration or growth within a population. Although data on lobster stocks off the east coast of England is limited, research has shown that stocks do not appear to be critically over fished, and in general it seems that current levels of effort are fishing at, or close to, the maximum sustainable yield. Offshore grounds are more heavily fished and as a possible result the average size of lobster has decreased since 2004. The future



Figure 2.10.23: The European lobster, *Homarus gammarus*
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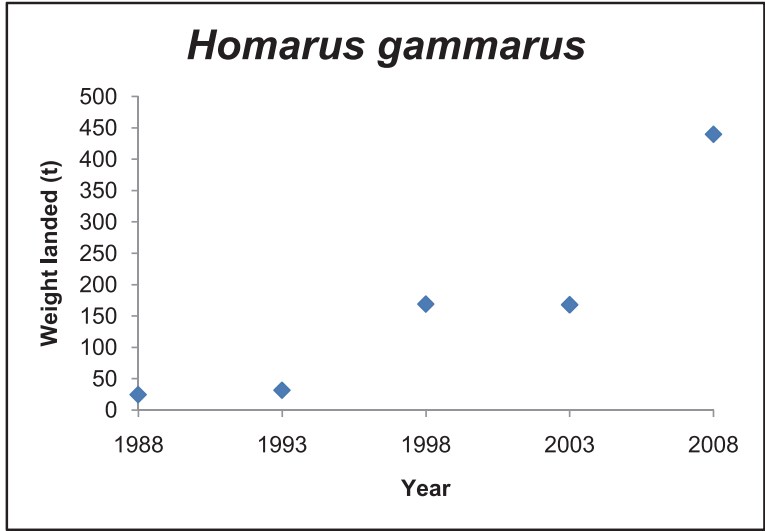


Figure 2.10.24: Lobster landings 1988–2008 (MMO data, 2008).

success of this lucrative fishery depends on future recruitment (Jessop *et al.* 2008).

Potting for lobsters is allowed by written consent from the Eastern and North Eastern Sea Fishery Committees. During 2007 the NESFJC initiated a major project to investigate local lobster populations. The aim of this study is to assess the size structure and status of the local lobster fishery, with the objective of gaining achieving Marine Stewardship Council (MSC) accreditation (NESFC 2008).

Brown Shrimp — *Crangon crangon* & *Crangon allmanni*

The brown shrimp, *Crangon crangon* (Figure 2.10.25, left) is ventrally flattened with mottled dark brown and grey colouration, and a short rostrum. This species is often confused with *Crangon allmanni* (Figure 2.10.25, right) which is associated with slightly



Figure 2.10.25: The brown shrimp, *Crangon crangon* (left) or *Crangon allmanni* (right) @ seasurvey.co.uk

deeper waters, but is also landed and recorded as brown shrimp. It feeds nocturnally, with the aid of chemoreceptors, on algae, small polychaete worms, small crustaceans and fish larvae (Moen & Svensen 2004). They can grow up to 90 mm in length, but are usually found to reach between 50–70 mm. Brown shrimp are found on all British coasts, often partially buried in fine gravel or sand, usually at around 10 m depth. Breeding of this species occurs biannually. Juveniles settle on intertidal mudflats after spending around 5 weeks in the plankton (Moen & Svensen 2004; Kuipers & Dapper 1984). They are an important prey item for many commercial fish species such as sole, dab, whiting, and especially cod which feed extensively on this species (Pinnegar & Stafford 2007).

Brown shrimp are abundant in The Wash (ESFJC reported 625 t landed from The Wash 2008 (Mander *et al.* 2008)) and are fished in large numbers from the Humber estuary (MMO landings data, 2008). Brown shrimp are likely to be limited to inshore areas of the Humber REC region as offshore deposits are gravelly and the sediment preference of brown shrimp is for a high proportion of sand and silt (Boddeke 1996; Pihl & Rosenberg 1984).

Pink Shrimp — *Pandalus montagui*

Pink shrimp, which is mainly *Pandalus montagui*, are larger than the brown shrimp, growing up to 160 mm in length. They are semi-transparent with a long serrated rostrum and females occasionally bear turquoise eggs (Figure 2.10.26). They feed on small molluscs, crustacean larvae, copepods and algae (Warren



Figure 2.10.26: The pink shrimp, *Pandalus montagui* @ seasurvey.co.uk

1973; Moen & Svensen 2004). Pink shrimp are common to depths of 15 m with established adults living even deeper. They are detritus feeders, usually found on hard bottom substrates, often in association with algae (Moen & Svensen 2004). In the winter pink shrimp migrate offshore to deeper water, returning to shallower waters in spring. Females brood eggs in the deeper water and return to inshore waters once they have spawned. The eggs hatch in March and the juveniles move inshore over the summer (Warren 1973). Within the REC area the deeper waters of the Silver Pit appear likely to represent an important brooding and winter-feeding grounds. The deep channel of the Silver Pit is known to support a significant pink shrimp population (MESL 2003) and the deeper channels of the Wash also hold large numbers (Warren 1973). The main adult fishery appears to be limited to inshore areas. Landings of the pink shrimp mainly originate from the Wash area (MMO landings data, 2008). The local shrimp fishery use a separation device which select shrimp and discard juvenile flat fish back into the water.

Norway Lobster — *Nephrops norvegicus*

The Norway lobster or Dublin Bay prawn, is a decapod crustacean with light orange colouration, kidney shaped eyes, and a long thin spiny rostrum. Males are larger than females, and can grow up to 250 mm in length. They are a small sublittoral, burrowing lobster which matures at 3 years of age.

In the UK mating occurs annually during the summer after the female has moulted. The eggs are laid in the autumn and attached to the pleopods where they are brooded for 9 months (Farmer 1974). Hatched larvae are free swimming for up to 60 days in temperate waters. The juvenile then metamorphoses into a burrowing post larvae when it reaches a size of approximately 15 mm.

Feeding experiments have shown pelagic larval stages to be carnivorous (Rotllant *et al.* 2001). Adults are opportunistic carnivorous feeders which mainly feed on crustaceans but will also feed on polychaetes and echinoderms (Cristo & Cartes 1998; Parslow-Williams *et al.* 2002). They usually inhabit depths between 40–800 m, often in habitats where soft mud is the dominant substrate (Moen & Svensen 2004). The distribution is limited by suitable sediment for burrowing, and adult individuals do not migrate.

The majority of the *Nephrops* fishery is based north of the REC area, mainly landed in ports such as Scarborough and Whitby. The fishery predominately uses bottom trawl although *Nephrops* are also caught using seine nets and pots (Cotter *et al.* 2004). The fishery mainly occurs in Silverpit, which is part of the larger area Botney Gut. Historically this species was exploited mainly by Belgium fisheries although in recent years British and Dutch vessels have become the most important exploiters of the area (ICES 2008). Landings within the Humber REC area reached a value of £88 000 in 2008 (Table 2.10.6). Landings do not indicate a declining trend, which may be due to a lack of commercially fished predators. However, mean sizes of males are getting smaller, whereas female sizes have stabilised. Differences in the catch between the sexes is common in *Nephrops* fisheries, with fewer females caught during much of the year as they remain burrow bound when carrying eggs. Overall, however, the size of both sexes are smaller than at the beginning of the 1990s, indicating an increased fishing pressure.

Velvet Swimming Crab — *Necora puber*

The velvet swimming crab, *Necora puber*, as its name suggests, has short hairs on its carapace that give it a velvety texture, and the last segment of its back legs are paddle shaped (Figure 2.10.27). It is very common on all British coasts, living from the intertidal zone down to approximately 70 m depth (Smith *et al.* 1994). The most prominent food source for this species is brown algae. However, depending on habitat depth and availability it will feed on molluscs and other smaller crustaceans (Norman & Jones 1992). This species is an important prey item for demersal species such as cod, roker and grey gurnard.

Velvet swimming crab are caught and landed as by-catch from both trawling and potting activities. Landings are usually exported to southern Europe, where they are popular and considered a delicacy. Crashes in the populations of the Spanish and French velvet swimming crab fisheries, have resulted in the high value for this fishery (Fahy *et al.* 2008).

As landings are almost entirely destined for the southern European market, fishing of velvets on the north Norfolk coast is timed with Scottish transit trucks which will accept the catch at Wells on certain days. This is considered a new fishery, though it has



Figure 2.10.27: The velvet swimming crab, *Necora puber*.

grown considerably in the last 10 years, with increased landings in the REC area. It is difficult to estimate the state of the velvet swimming crab fishery as landings have historically been recorded as 'Other Shellfish'. In recent years the population of the velvet swimming crab along the coasts of Yorkshire and Norfolk has increased (Lawler, Firmin & Bell 2006). Recent developments in storage units will undoubtedly encourage more effort to be put into targeting velvets (Jessop *et al.* 2008). Landings of *N. puber* have increased from minimal landings recorded in the 1990s to 162 t in 2008 (Table 2.10.5). Although there is no long term data available, Eastern Sea Fisheries research has shown a notable reduction in numbers of velvet swimming crabs. There has been a consistent fall in yield over the past five years (Jessop, 2009). The rapid growth of this fishery means that stock levels will probably need to be closely monitored.

Common Green Shore Crab — *Carcinus maenas*

The common shore crab, *Carcinus maenas*, is a fast moving dark brown or green crab. It is common in the intertidal zone, brackish waters and occasionally deep waters on all UK coasts. The shore crab can grow to a carapace length of up to 80 cm, but are usually seen to be about 60 cm. Gravid females are found all year round (Moen & Svensen 2004). They constitute a small fishery within the REC area, and are used as bait for bass fishing by anglers (Sheehan *et al.* 2008).

Mollusca

The mollusc fishery contributes a large amount to the total landings originating in the Humber REC area. Whelks contribute to the majority of the landings from offshore areas (Figure 2.10.2).

The Wash, which borders the REC boundary, has an important mussel and cockle fishery. Within the Wash area there are discrepancies between MMO landings data and landings data reported by the ESFJC. The ESFJC have reported a landing weight of 2 049 t for mussels (*Mytilus edulis*) and 4 948 t for cockles (*Cerastoderma edule*) (Mander & others 2008) whereas the MMO report 349 t for mussels and have not recorded any landings of cockles (MMO landings data, 2008). The weights reported by the ESFJC are based on landings from Boston and Kings Lynn, vessels based at these ports fish the Wash almost exclusively. The reason for the large differences in landings data maybe because there is no national quota for cockles and mussels. As a result, there is little need for the MMO to acquire accurate landing data from the fishermen. However, the Wash is regulated by ESFJC under the Wash Fishery Order, and as such they manage the access to, and monitor uptake of, the fishery. The fishery is regulated by specific opening seasons (which are subject to appropriate assessment), a TAC which is usually allotted to both the dredge fishery (if running) and handwork fishery, and gear restrictions. Landings data for the blue mussel and the common cockle are probably more accurate from the local sea fisheries committee. The ESFJC data is more reliable than data collected by the MMO, who have less of a presence in terms of management and enforcement of the local mollusc shellfisheries. When regarding The Wash, ESFJC figures will be quoted in the following section as they are more likely to represent true weights landed.

Bivalves and Gastropods

Blue Mussel — *Mytilus edulis*

Blue mussels, *Mytilus edulis*, are gregarious in nature and form extensive beds which may be up to 6 layers deep. They inhabit areas of hard and soft substratum, usually down to 10 m depth and have a tolerance for a large range of temperature and salinity. Healthy individuals may reach up to 100 mm in length (Figure 2.10.28). The individuals are held in place by their byssal threads



Figure 2.10.28: The blue mussel, *Mytilus edulis*
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and young mussels colonise any spaces, which acts to further stabilise the beds and also increases complexity (Moen & Svensen 2004). Mussels are filter feeders of suspended microscopic animals and organic material in the water column.

Mussels are gonochoristic, with separate males and females, and they spawn over a protracted period, peaking in spring and summer. One mussel can release up to 10 million eggs, and larvae can settle on almost any type of substrate. Mussel larvae remain in the water column for between one and six months before settling onto a hard surface. Mussels are capable of limited movement by detaching and reattaching their byssus threads which anchor them to the seafloor but they are essentially sedentary in nature (Moen & Svensen 2004).

Mussel beds are found on areas of mud, sand and pebbles throughout the Wash. Fishermen sow subtidal mussel seed both within the Wash and in harbours along the North Norfolk Coast (English Nature. 2000). They are mainly harvested during the winter when the flesh is of high quality (Walmsley & Pawson 2007). Mussels are hand collected and dredged using 'Baird' dredges along the Norfolk coast. A mesh size of 50 mm is imposed on fishermen, except in the wash where it is 45 mm. Over the last 30 years wild stocks have decreased due to fishing pressure and low recruitment.

The Wash is by far the most important area for mussel stocks in the Humber REC area, with landings reaching almost 350 t for 2008 (MMO landings data, 2008). However, landings of 4 483 t with an associated value of over £1.2 million have been reported

by ESFJC (Mander & others 2009). A Survey during 2009 found that the mussel stock of the Wash to be 15 188 t which is a significant improvement from 2008. Over half of the stock was at a marketable size (≥ 45 mm). Although the stock weight has increased, the area covered by the mussels has decreased. This higher density of mussels is a trend which has been seen since 2005 (Jessop R W 2009).

Using local byelaws North Eastern and Eastern Sea Fisheries Joint Committee regulate the mussel fishery and have imposed various restrictions on fishing practices, vessel size, the areas which can be fished and the maximum size which can be taken.

Cockles — *Cerastoderma edule*

The common cockle *Cerastoderma edule*, is a moderately sized bivalve mollusc (Figure 2.10.29). They are found in shallow burrows in soft sediments, ranging from soft muds to gravels, from the mid to lower intertidal and sometimes subtidally. They usually live at salinities between 15–35 psu but can tolerate salinities as low as 10 psu and are often abundant in estuaries and sheltered bays. The cockle filter feeds on organic material (microscopic plants, animals, and debris) suspended in the water column.



Figure 2.10.29: The common cockle, *Cerastoderma edule*
@ seasurvey.co.uk

Cockles are either male or female, though there is little obvious morphological difference between them. Cockles spawn mostly in early spring, but may continue to some extent throughout the summer and even into autumn. Eggs and sperm are released into the water column where the developing larvae remain for about three weeks. The larvae settle en-masse when they reach about 1mm in size. Young cockles, known as 'spat' are easily moved and redistributed from the seabed by tides until they reach about 4 mm in size. At this stage they are able to anchor themselves using their muscular foot. Once settled, cockles are unlikely to move voluntarily for the rest of their lives. Recruitment varies annually (Franklin 1972). It is not known whether cockles are able to select their place of settlement but the presence of vast accumulations of cockles in situations unsuitable for growth and survival suggests that this is a passive process occurring when the cockles are large enough to sink to the seafloor.

Cockles reach maturity after about one year and may live for more than ten years, although a lifespan of four to five years is more common in commercially exploited beds (Franklin 1972).

Within the Humber region cockle stocks are between 20 000 and 30 000 t and an estimated 2 088 t of cockles (worth over £0.5 million) were landed in Kings Lynn and Boston ports in 2009 (Mander & others 2009). On the southwest border of the Humber REC lies The Wash, a highly important area for the cockle fishery where cockles are mainly harvested by hydraulic suction dredger. Occasionally, by order of the ESFJC this method is banned and instead the traditional methods of either hand collecting or using propellers to concentrate cockles into a group on the seafloor are used. The Eastern Sea Fisheries Committee may also impose seasonal closures to conserve stocks, a scheme which is supported by local fishermen (Walmsley & Pawson 2007).

The cockle population has declined over the past decade due to decreased settlement and low recruitment of spat. Cockles are collected by hand on the North Yorkshire coast, and an increase in the cockle fishery has been seen with rise in demand. Intertidal flats in the Wash support large stocks of cockles, which has historically supported a major fishery.

Whelks — *Buccinum undatum*

Whelks, *Buccinum undatum* (Figure 2.10.30), are common in the UK and are found mostly sub-tidally down to 1200 m. They are found on muddy sand, gravel and also rocks and are sometimes present in brackish water (down to a salinity of 14). Whelks do not make significant migrations, but some effort may be made by females to find coarse seabed features, such as rocks, stones and shells, on which to attach egg masses. The females lay small masses of lentil shaped eggs in the winter or spring (Moen & Svenson, 2004). About 13–14 young emerge as miniature adults from each egg mass, and disperse by crawling away (Hancock 1967; Martel & Larrive 1986).

A thriving fishery for whelks exists in the Humber REC area up to 30 miles offshore and the species is targeted mainly with pots. Landings from the Humber REC region have been very high with 2800 t landed in 2003 although only 350 t were landed in 2008. Increased fishing of the whelk was found to have a negative impact on populations and this may be a reason for the decrease in catch (Morel & Bossy 2004). On the Yorkshire coast whelks are fished more intensively with pots, Bridlington is a main port for this fishery where whelk fishing occurs all year round. Inshore whelk fishing is permitted by written consent only issued by the North East Sea Fisheries Committee (Walmsley & Pawson 2007). A large proportion of the whelk stock is exported.



Figure 2.10.30: The whelk, *Buccinum undatum*
@ seasurvey.co.uk

King & Queen Scallops — *Pecten maximus* & *Aequipecten opercularis*

The queen scallop, *Aequipecten opercularis*, and the larger king scallop, *Pecten maximus* (Figure 2.10.31), are most commonly encountered on coarse substrates dominated by gravel or shell (Moen & Svensen 2004). Despite the mobility of scallops, they are sedentary for most of their life, and thrive in areas of moderate current. They spawn between spring and autumn although there is considerable regional variation.

Queen scallops make the largest contribution to the scallop fishery in the Humber REC area, (Walmsley & Pawson 2007) in some cases exceeding 50 t annually (MMO data, 2008). They are dredged off the Yorkshire coast as well as being taken as by-catch by demersal trawlers. There are a few local boats that target this species during the winter months. King scallops are also fished, in increasing numbers, from autumn to early summer. King and queen scallops are both non-quota species but do have EU regulatory minimum landing sizes of 100 mm & 40 mm respectively in the southern North Sea. The NESFJC have imposed a byelaw which prevents the use of scallop dredgers inside 3 nautical miles of the Yorkshire coast.

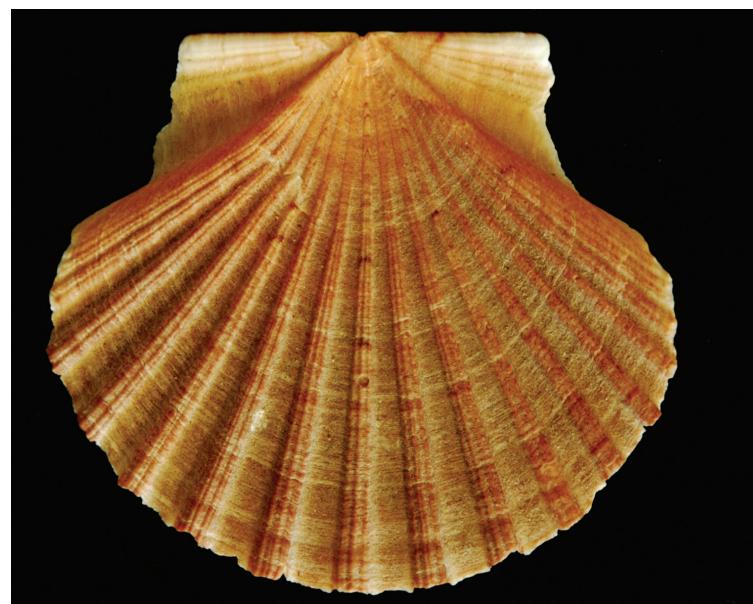


Figure 2.10.31: King scallop, *Pecten maximus*
@ seasurvey.co.uk

Pacific Cupped Oyster — *Crassostrea gigas*

The Pacific oyster, which originated from Japan, is a very successful invasive species (Brandt, Wehrmann & Wirtz 2008) that has established populations after mariculture was established. The shell can grow to 18 cm in length and they are found at depths of between 10 and 80 m. The species has a wide tolerance to environmental conditions, and is therefore chosen for mariculture all over the world. The Pacific oyster is an estuarine species with an optimum salinity range between 20–25 although it can occur at salinities below 10 and above 35. It prefers hard substrates although it will also attach to rocks, debris and shells. Larvae are planktonic and distributed through out the water column. There were no recorded landings of this species in 2008, but previous years have seen landings of between 4 and 26 t (MMO data, 2008).

2.10.5 Elasmobranchs — Sharks, Rays and Batoids

The cartilaginous fish are collectively known as the Chondrichthyans. They are distinguished from the bony fishes by an internal skeleton formed from cartilage and from jawless fishes by their true upper and lower jaws. The taxonomic class Chondrichthyes is divided into two subclasses: the Elasmobranchii (sharks, skates and rays) and the Holocephali (chimaeras). The elasmobranchs are further divided into three superorders, the Galeomorphii, the Squalomorphii (Sharks) and the Batoidea (skates and rays). The sharks are distinguished from skates and rays by the position of their five, six or seven gills on the sides of their body, rather than on the underside of the body, and the pectoral fins being separate from the head.

In the Humber REC there are 13 out of a possible 35 species of shark, and 5 out of a possible 21 species of ray known to be present in UK waters. Of these species, 13 are considered threatened and are listed in the Global Red list as Critically Endangered, Endangered or Vulnerable according to the IUCN criteria (IUCN 2010) (Table 2.10.7).

The impact of fishing on elasmobranch stocks around the world is currently the focus of considerable international concern. Few elasmobranch species are specifically targeted but many species are considered as an important component of fisheries by-catch (Table 2.10.8) because of the high commercial value of their meat, skin, liver and fins (Table 2.10.9).

The K-selected life-history characteristics of Elasmobranchs (they mature late and produce few young after a long gestation period) make them intrinsically vulnerable to fishing pressure (Dulvy *et al.* 2008). Once overfished, shark and rays populations would take several decades to recover. Studies on trends in elasmobranch abundance during the last century show that numbers of large bodied skates and sharks have been constantly decreasing (Rogers & Ellis 2000).

Many threatened pelagic shark species, including the thresher shark *Alopias* spp., the mako shark *Isurus* spp. and the porbeagle *Lamna nasus* are commercially exploited. The blue shark *Prionace glauca* is also assessed as Near Threatened. These species are a valued bycatch of pelagic fisheries targeting tuna and billfishes and are also targeted for their meat and fins when traditional fishing targets are less available (Camhi *et al.* 2009). The combination of intense fishing efforts (due to the rising value of shark products) and low reproductive rates has led to severe declines in these species' populations (Dulvy *et al.* 2008). Near Threatened pelagic sharks include several deepwater species such as the frilled shark *Chlamydoselachus anguineus*, and the bluntnose sixgill shark *Hexanchus griseus*. Deepwater elasmobranchs tend to have particularly low reproductive potential and therefore a high vulnerability to depletion by fisheries (Camhi *et al.* 2009; Compagno 2008).

In trawling fisheries the common and the white skate (*Dipturus batis* and *Rostroraja alba*), the angel shark *Squatina squatina* and other rays of intermediate body size showed marked declines in relative abundance, especially the blonde ray *Raja brachyura* and the thornback ray *Raja clavata*. Consequently, current batoid catches comprised mainly smaller species such as the spotted ray *Raja montangui*, the cuckoo ray *Leucoraja naevus* and lesser spotted dogfish shark *Scyliorhinus canicula* (Rogers & Ellis 2000).

Some 50% of the estimated global catch of elasmobranchs is taken as by-catch and does not appear in official fishery statistics. Landing records in most countries are scarce and actual landings are highly underestimated and few countries have any form of management for these resources. Compounding the problem is the oceanic and highly migratory nature of many species, placing them outside the responsibility of individual countries and outside the mandate of international bodies, which were mostly set up for the management of tuna (Stevens *et al.* 2000).

Improved monitoring and further research is needed to further our understanding of elasmobranchs, particularly of the Near Threatened and Threatened species and management action is needed to prevent them from becoming listed as Threatened in the future.

All general distribution information has been taken from the Shark Trust identification guides (Shark Trust 2009; Shark Trust 2010). The species of elasmobranchs that have been recorded in the area of the Humber REC are listed below. For each species we give a short description of its habitat and distribution, commercial importance and conservation status. A brief schematic summary is also given in Table 2.10.7.

Pelagic Sharks

Thresher Shark — *Alopias vulpinus* (Bonaterre, 1788)

There are three species of thresher shark in the family Alopiidae: the pelagic thresher *Alopias pelagicus*, the bigeye thresher *A. superciliosus* and the thresher shark *A. vulpinus*. All three are highly migratory and found in both coastal and oceanic waters in temperate and tropical seas although *A. vulpinus* tends to be more temperate and the most coastal of the three. Thresher sharks provide high-quality meat and *A. vulpinus* is the preferred species of the three (Rose 1996). Although their fins are not highly valued, threshers collectively account for 2.3% of the identified shark fins in the Hong Kong fin market. Thresher liver oil is considered poor quality but usable; their skins are used for leather (Rose 1996). Threshers are listed in Annex I of the United Nations Convention on the Law of the Sea (UNCLOS), and therefore should be subject to the specified provisions for international fisheries management. In reality, few management measures have been adopted for these species in international or national waters. Baum *et al.* (2003) estimated that thresher sharks (*A. vulpinus* and *A. superciliosus* combined) have declined by 80% from 1986 to 2000 in the northwest Atlantic. Targeted commercial fisheries for thresher sharks are uncommon; these sharks are often by-catch of the swordfish and other pelagic fisheries (4–12 t per year since 2000 in the UK) and are also targeted by recreational fishing (Camhi *et al.* 2009). The Red list status of this species is Vulnerable.

Basking Shark — *Cetorhinus maximus* (Gunnerus, 1765)

The basking shark, *Cetorhinus maximus*, (Figure 2.10.32) is the



Figure 2.10.32: Basking shark *Cetorhinus maximus*
© Sally Sharrock

world's second largest fish and feeds by obligate ram filtering on patches of large zooplankton such as the copepod *Calanus* in temperate shelf waters circumglobally (Sims, Fox & Merrett 1997).

There have been many sightings of basking sharks around the coast of the UK, mostly in the south-west, Scotland and the Irish Sea. Sightings in the North Sea are not well recorded but it is within the species known distribution range. Studies on the reproductive behavior of the species found that courtship-like behaviours occur annually off south-east England, suggesting that the area could be an annual breeding zone. Mating locations are associated with thermal fronts where individuals aggregate to forage in rich prey patches before initiating courtship. Reproductive maturity is achieved by adult individuals between 5 and 8 m total body length (Sims *et al.* 2005).

Basking sharks have been targeted for centuries to supply liver oil, leather, fins, meat and fishmeal leading to the collapse of many populations. The species is one of the few sharks listed by the Convention on International Trade in Endangered Species (CITES). Its listing is intended to ensure that international trade in basking shark products is not detrimental to the survival of the species. Basking sharks were also listed in Appendix I of the 2005 Convention on Migratory Species (CMS), which has led to their legal protection by many States that are a Party to this treaty. The co-operative management should be introduced under the listing in Appendix II of the CMS. The species is also listed in Annex I of UNCLOS.

Species name	Common name	Habitat	Distribution		Catch	Red List	
Galeomorphii						Global	Regional
<i>Alopias vulpinus</i>	Thresher shark	P	NE ATL, MED	RE, IB	VU	NT	NT
<i>Cetorhinus maximus</i>	Basking shark	P	NE ATL, MED		VU	VU	EN
<i>Galeorhinus galeus</i>	Tope	DoP	NE ATL, MED	TA, RE	VU	DD	DD
<i>Galeus melastomus</i>	Blackmouth catshark	DoP	NE ATL, MED	UB	LC		
<i>Lamna nasus</i>	Portbeagle shark	P	NE ATL, MED	TA, RE	CR	VU	VU
<i>Mustelus asterias</i>	Starry smoothhound	DoP	NE ATL, MED	IB, TA, RE	LC		
<i>Prionace glauca</i>	Blue shark	P	NE ATL, MED	TA, RE	NT		
<i>Scyliorhinus canicula</i>	Dogfish (smallspotted catshark)	D	NE ATL, MED	UB, RE	LC		
<i>Scyliorhinus stellaris</i>	Nursehound	D	NE ATL, MED	IB, RE	NT		
Squalomorphii							
<i>Dalatia licha</i>	Kitefin shark	DoP	NE ATL, MED	TA	NT	VU	VU
<i>Hexanchus griseus</i>	Bluntnose sixgill shark	DoP	NE ATL, MED	IB	NT		
<i>Scymnodon ringens</i>	Knifetooth dogfish	DoP	NE ATL	UB	DD		
<i>Squalus acanthias</i>	Spiny dogfish	D	NE ATL, MED, BLK	TA	CR	VU	VU
Batoidea							
<i>Dasyatis pastinaca</i>	Common stingray	D	NE ATL, MED, BLK	UB, RE	NT	DD	DD
<i>Leucoraja naevus</i>	Cuckoo ray	D	NE ATL, MED	UB	NT	LC	LC
<i>Raja brachyura</i>	Blonde ray	D	NE ATL, MED	IB	NT		
<i>Raja clavata</i>	Thornback ray	D	NE ATL, MED, BLK	TA, RE	NT		
<i>Raja montagui</i>	Spotted ray	D	NE ATL, MED	IB	LC		

Table 2.10.7: Habitat, distribution, commercial importance and Red List status of elasmobranch species recorded in the Humber REC study area. KEY: Habitat: P - pelagic, D - demersal, DoP - demersal occasionally pelagic; Distribution: NE ATL - north-east Atlantic, MED - Mediterranean, BLK - Black Sea; Catch: IB - important by-catch, RE - recreational, TA - targeted by fisheries, UB - unimportant by-catch; Red List status: CR - critically endangered, EN - endangered, VU - vulnerable, NT - non-threatened, LC - low concern, DD - data deficient.

Target fishing for basking sharks in the Northeast Atlantic ceased in 2006, in line with ICES advice and the CMS Appendix I listing, when retention of the species was legally prohibited throughout the European Union and Norway closed its basking shark fishery. The basking shark is also listed in the Appendices and Annexes

of several regional Conventions (Barcelona, Bern and OSPAR) (Camhi *et al.* 2009). The Red list status of this species is vulnerable on a global scale, and endangered regionally.

Porbeagle Shark — *Lamna nasus* (Bonaterre, 1788)

The porbeagle shark, *Lamna nasus*, is found in coastal and offshore temperate waters of the North Atlantic and in the southern hemisphere, where it is circumglobal. The porbeagle shark is a piscivore, preferring pelagic fish and cephalopods where abundant.

Unlike many other pelagic sharks, porbeagles have been intensely targeted since the 1920s (Francis *et al.* 2008). They are sought primarily for their high-quality meat, skin for the production of leather and for liver oil (Rose 1996; Francis *et al.* 2008). In the 1960s, reported worldwide porbeagle landings were 10 times what they are today. In the northwest Atlantic, the population hovers at about 11% of its 1961 virgin biomass. Scientists estimate that even if target fisheries were closed and strict limits placed on porbeagle bycatch, it could take at least 30–60 years for this population to recover. One potential factor exacerbating population declines is area fidelity to coastal waters where fisheries are intensive (Camhi *et al.* 2009).

Vulnerability is higher throughout the summer when the species aggregates (Pade *et al.*, 2009). With the exception of the widely protected whale, white and basking sharks, porbeagle is subject to more species specific management than any other pelagic shark. This is probably due to their high value and exceptionally depleted status in several regions. The species is considered to be at moderate risk of overexploitation. In the north Atlantic, however, decades of target and incidental fishing have taken a serious toll on porbeagle sharks, resulting in Red List assessments of Critically Endangered in the northeast Atlantic and Mediterranean and Endangered in the northwest Atlantic (Camhi *et al.*, 2009).

Blue Shark — *Prionace glauca* (Linnaeus, 1758)

The blue shark *Prionace glauca* (Figure 2.10.33) is widely distributed in temperate and tropical waters between 60°N and 50°S, although abundance increases with latitude (Compagno 1984; Nakano and Stevens 2008). Habitually they are pelagic, found from the surface to 600m with a temperature preference of 12–20°C. They segregate by sex.

This transoceanic migrant (Kohler and Turner 2008) may be the world’s most abundant pelagic shark. However, it is also the shark

Common name	Scientific name	1988 (t)	1993 (t)	1998 (t)	2003 (t)	2008 (t)
Blonde Ray	<i>Raja brachyura</i>					1
Dogfishes and hounds	<i>Squalidae, Scyliorhinidae</i>	0.1	0	0		0
Picked dogfish	<i>Squalus acanthias</i>	412	143	23	6	0
Raja rays	<i>Raja</i> spp.	187	213	118	48	19
Smooth-hound	<i>Mustelus mustelus</i>				0	0
Spotted Ray	<i>Raja montagui</i>					1
Thornback Ray	<i>Raja clavata</i>					11
Tope	<i>Galeorhinus galeus</i>	1	2	0	0	0
Various sharks	Selachimorpha (Pleurotremata)	0	0	0	0	

Table 2.10.8: Annual total live weight (t) of elasmobranchs landed into various UK ports originating from ICES statistical rectangles encompassing the Humber REC area for years 1988, 1993, 1998, 2003 & 2008 (MMO landings data, 2008).

Common name	Scientific name	1988 (£)	1993 (£)	1998 (£)	2003 (£)	2008 (£)
Blonde Ray	<i>Raja brachyura</i>					1 031
Dogfishes and hounds	<i>Squalidae, Scyliorhinidae</i>	40	0	12		15
Picked dogfish	<i>Squalus acanthias</i>	275 498	155 867	33 631	6 576	174
Raja rays	<i>Raja</i> spp.	133 041	237 694	142 105	47 738	25 038
Smooth-hound	<i>Mustelus mustelus</i>				13	225
Spotted Ray	<i>Raja montagui</i>					1 038
Thornback Ray	<i>Raja clavata</i>					16 037
Tope	<i>Galeorhinus galeus</i>	272	1 224	304	93	11
Various sharks	Selachimorpha (Pleurotremata)	702	509	42	69	

Table 2.10.9: Annual total value (£) of elasmobranchs landed into various UK ports originating from ICES statistical rectangles encompassing the Humber REC area for years 1988, 1993, 1998, 2003 & 2008 (MMO landings data, 2008).

taken in the greatest numbers in pelagic longline and net fisheries, especially those targeting tunas and billfishes (Camhi *et al.* 2009; Dulvy *et al.* 2008). Historically, blue sharks were rarely targets of commercial fisheries and were traditionally discarded in huge numbers as unwanted by-catch because of the low desirability of their flesh. Since the late 1980s, however, the growing demand and high prices paid for shark fins have resulted in the increased

retention of blue sharks. Other fisheries are now targeting blue sharks, particularly when their teleost or higher-value shark targets are less available (Camhi *et al.* 2009).

Today, blue sharks account for over 55% of pelagic shark landings reported to species and fishing pressure will continue to grow as other target and secondary target species become less available



Figure 2.10.33: Blue shark *Prionace glauca* © Sally Pitkin

and the price paid for shark fins increase (Camhi *et al.* 2009). Blue sharks are the dominant species in the global shark fin trade (17% of the Hong Kong fin market — Clarke *et al.* 2006b) and are a preferred species for leather and cartilage products (Rose 1996). Recently, there has been a push to develop new markets for blue shark meat and other products. There are no species-specific catch limits or other protections for blue sharks in international waters, despite their prominence in international trade (Rose 1996; Clarke *et al.* 2006a, 2006b). The blue shark is currently listed as Near Threatened in the Red List, with considerable support for a Vulnerable listing, at least for the north Atlantic. The species has a moderately high reproductive rate (Dulvy *et al.* 2008; Cortes 2010; Smith *et al.* 2008), widespread distribution, opportunistic feeding behaviour (Stevens *et al.*, 1973) and abundance in all oceans suggest resilience, but not immunity, to overfishing and endangerment. The transoceanic migrations of blue sharks strongly support arguments for regional and international management to ensure that populations of this abundant species are not depleted. Survival on longlines at gear retrieval is relatively high (69–90%), suggesting that mandatory release in conjunction with finning bans can be an effective tool to reduce blue shark fishing mortality (Camhi *et al.* 2009).

Demersal — Occasionally Pelagic Sharks

Dogfish & Triakid Sharks

Dogfish and triakid sharks (tope and smooth hounds) are widely distributed in the southern North Sea, an area where both lesser spotted dogfish (*Scyliorhinus canicula*) and smooth hound (*Mustelus mustelus*) numbers have been seen to be on the increase (data from surveys, landings and recreational fishing

(ICES. 2009). Dogfish are not a popular commercial species due to heavy processing and low market value. The success of dogfish may be attributed to its high survival rate, quoted to be as high as 98%, in beam trawl discards (Revill, Dulvy & Holst 2005).

Tope Shark — *Galeorhinus galeus* (Linnaeus, 1758)

Galeorhinus galeus is a widespread, mainly coastal- and bottom-associated shark of temperate areas, which has been fished in all parts of its distribution. They are highly migratory, moving towards the poles in summer. Tope are found in shallow waters to depths of about 550 m. Their habit is predominantly demersal but they may also be caught on pelagic longlines. The species segregates by sex, except during mating periods. The diet of the tope is a variety of bony fish, elasmobranchs and squid, and they do not appear inclined to scavenge.

Tope are vulnerable to overfishing due to late maturity and low reproductive potential. Its status varies depending on the region. In the northeast Atlantic *G. galeus* is typically a by-catch of mixed demersal and pelagic fisheries. In Europe, this species is important in recreational fisheries. Commercially they are a widely fished shark species, taken as by-catch and targeted where abundant. The shark flash, fins and liver oil are all utilized. Biological data for northeast Atlantic stocks are limited and the species has an ICES Data Deficient status indicating that further investigation into its status is required.

Starry Smoothhound — *Mustelus asterias* (Cloquet, 1821)

This species is distributed in the northeast Atlantic from the British Isles and North Sea to Mauritania and the Canary Isles, including the Mediterranean Sea. It's a small oviparous species (78–85 cm) with a gestation period of 12 months and litters of 10–35 pups being recorded. Starry smoothhounds are found in shallow waters to more than 100 m and they hunt for crustacean prey along the bottom, rarely moving into the water column. It seems they prefer softer sediments such as sand and gravel. The species is increasingly targeted as more valuable shark species disappear and they may come under increasing pressure in the future. Commercially they are of little importance in northern Europe, but the flesh is sometimes eaten in Germany and France. They are often a bycatch species in Atlantic bottom trawls, gillnet and line

gear. They are a popular catch with anglers and can be caught from the shore. Their Red list status is of Least Concern.

Dogfish (Smallspotted Catshark) — *Scyliorhinus canicula* (Linnaeus, 1758)

Dogfish are small demersal sharks, covered in small dark spots, which usually grow to 60–70 cm (Figure 2.10.34). Mating commences in autumn. Dogfish spawn in a similar manner to that of skates, i.e. 'mermaid's purse' egg cases, although a longer incubation period is observed. They are nocturnal opportunistic feeders, feeding mainly on decapod crustaceans and euphausiidae shrimps, but also on demersal and pelagic fish. They are also scavengers and have been recorded feeding on discards from fisheries (Olaso *et al.* 2002; Revill *et al.* 2005). Dogfish are commonly distributed throughout the UK, often discarded as by-catch with a survival rate of 98% at release. Redlist status is of Least Concern.



Figure 2.10.34: Dogfish *Scyliorhinus canicula*.

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Nursehound — *Scyliorhinus stellaris* (Linnaeus, 1758)

The nursehound is found in the northeast Atlantic from southern Scandinavia and the British Isles to Morocco, including the Mediterranean Sea. It can be found from the intertidal region but is most common at depths 20–63 m with a preference for rough and rocky areas or habitats with heavy algal cover. It is oviparous, with incubation periods of 9–11 months. Cephalopods dominate

the diet of nursehounds although crustaceans, molluscs and fish are also important. It can be locally abundant, although not to the same extent as the dogfish. It is a by-catch species in the Atlantic in trawls. It may be vulnerable to overexploitation due to limited interconnectivity between populations and relatively low fecundity, but it can be locally abundant. The Red list status for this species is Near Threatened (2008).

Blackmouth Catshark — *Galeus melastomus* (Rafinesque, 1810)

The blackmouth catshark, is found in the East Atlantic and in the Mediterranean Sea. The species lives between 55–1200 m and is predominantly benthic. It can also feed in the water column. It also segregates by size with adults and juveniles found deeper than recruits. Blackmouth catsharks feed primarily on bottom invertebrates such as shrimp and cephalopods, and also on bony fishes and other small elasmobranchs. From a conservation perspective they are an abundant species with populations which appear to be stable. Their red list status is considered of Least Concern (2008). In commercial fishing, they are taken as bycatch in demersal trawl and longline fisheries and are generally discarded.

Kitefin Shark — *Dalatia licha* (Bonaterre, 1788)

The kitefin has a patchy distribution worldwide encompassing the East Atlantic from Scotland heading southwards along the coast. They are usually demersal but are often caught in the water column. The species is found at depths from 37–1 800 m but are most common below 200 m. They prey primarily on bony fish, along with crustaceans, chondrichthyans and squid. Also, stomach content analysis revealed large pelagic fish such as tuna and bonito. Kitefin sharks are extremely vulnerable to fishing pressure, they are targeted for the liver oil and are primarily used for fish meal in the East Atlantic. Red list status — Near Threatened (2008).

Bluntnose Sixgill Shark — *Hexanchus griseus* (Bonaterre, 1788)

This species is wide-ranging, although patchily distributed, in boreal, temperate and tropical seas. Juveniles are found close to the shore, while adults live down to depths of 2 200 m, this is why deep shore bays are used as nursery areas by this species. Adults have been known to move into shallow waters at night

to feed. They feed nocturnally on a wide range of teleost fish, elasmobranchs, crustaceans, molluscs and marine mammals. Bluntnose sixgill sharks are particularly vulnerable to fishing pressure due to their large size and naturally low abundance. These sharks are fished commercially and recreationally using line gear, trawls, traps and gill nets. The flesh is used for human consumption, the liver for oil and the carcass for fishmeal. Data on landings of this species is scarce, yet the Red list status is Near Threatened (2000).

Knifetooth Dogfish — *Scymnodon ringens* (Bocage & Capello 1864)

The knifetooth dogfish, *Scymnodon ringens*, is found in the East Atlantic from Scotland to Spain, Portugal and Senegal. Understanding of the knifetooth dogfish is poor, but it is most likely ovoviviparous and dentition suggests the ability to dismember relatively large prey. It lives in benthic to mesopelagic areas from 200–1600 m and is found on continental slopes. Commercially it is taken as by-catch and is of little interest and usually discarded. If it is landed it can be used for human consumption. There is no data available on landing although it is likely to be vulnerable to fishing pressure. Red list status — Data Deficient (2008) (IUCN 2010).

Common Spiny Dogfish — *Squalus acanthias*

The common spiny dogfish, *Squalus acanthias*, is a small to medium sized majestic shark with oval eyes and a pointed nose. Its identifying feature is a short spine in front of both dorsal fins.

The species is found in temperate waters, and is usually demersal with a preference for sand and mud, at depths ranging between 10 and 200 m, but specimens have been caught much deeper.

Spiny dogfish are highly migratory, following seasonal temperature gradients. Transatlantic migrations have occasionally been recorded and they segregate by size and by sex once mature. It is an ovoviviparous species. Feeding is extremely active, and it will attack schools of small pelagic fish as well as cod and other gadoid fish; it will also feed on large bottom-living fauna.

Spiny dogfish are very abundant, sometimes forming large shoals. However it is especially vulnerable to over-fishing as it is slow growing, has a long gestation period, and produces

a small number of young. It is marketed as flake and has historically been an important fishery from the REC area (Dipper, 2001). Landings are mostly from the mixed demersal fishery. Commercially they were previously a highly important species targeted across its range by bottom trawls, gillnets and longlines. Populations have fallen by 95% in some places due to overfishing and they are critically endangered in the northeast Atlantic. There is a huge demand in western Europe, particularly the UK. ICES has advised the stock is depleted and may be in danger of collapse. Targeted fisheries should not be permitted to continue, and by-catch in mixed fisheries should be reduced to the lowest possible level. Despite this advice the EC has set the UK quota for British waters to be 368 t. Red list status — Vulnerable (IUCN 2010) (2006).

Batoids

Thornback Ray — *Raja clavata* (Linnaeus 1758)

The thornback ray is the most common ray in the Humber REC study area. As the name suggests, it bears many spines along its dorsal side, especially along its tail (Figure 2.10.35). Individual colour varies, but is usually brown to mottled grey. The maximum

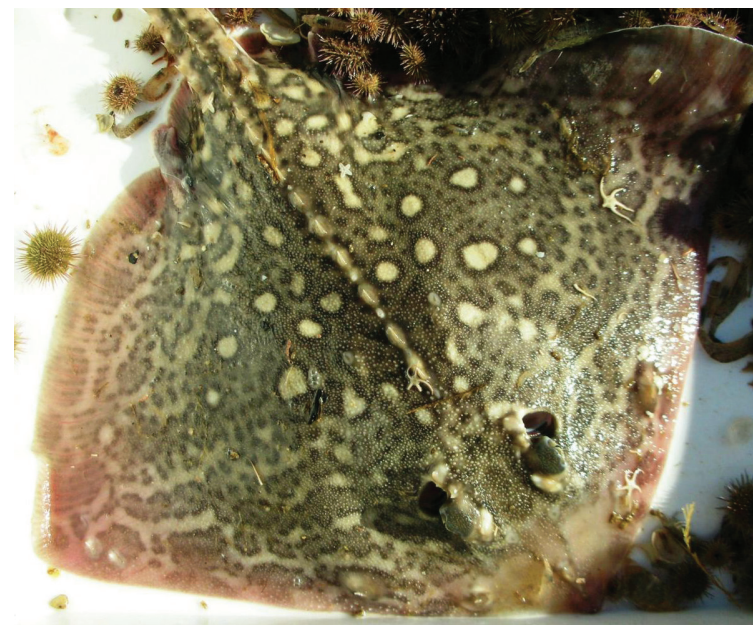


Figure 2.10.35: Thornback ray, *Raja clavata*.
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length is approximately 1 m but it usually ranges around 85 cm. *R. clavata* inhabits areas with mixed sand and gravel sediment and is most common between 10 and 60 m water depth. They tend to feed nocturnally on decapods crustaceans but will also feed on fish, urchins and polychaetes. Females lay around 20 eggs encased in 'mermaid's purse' shaped capsules (rectangular dark brown horned capsules between 6 and 9 cm in length). Spawning occurs throughout the spring and summer months. The egg capsules will take 4–5 months to hatch at which point the juvenile will be approximately 8 cm in width (wing tip to wing tip) (Dipper 2001). As with other elasmobranchs, growth is slow and maturity is reached at 7–9 years. Rays are a major fishery in the REC area, 20 t fished mainly with the use of demersal trawls, were landed in 2008. The species range appears to have contracted, particularly in the North Sea. Its Red List Status is Near Threatened.

Blonde Ray — *Raja brachyura* (Lafont 1873)

This large skate is distributed demersally up to 900 m depth. It matures late, has a long incubation period and a low fecundity. Moreover, since it prefers soft substrates such as sand or mud it is concentrated in specific grounds and is consequently vulnerable to localised exploitation. It is a targeted species of multispecies trawl, longline and gillnet fisheries. Blonde ray's status at present is Near Threatened.

Common Stingray — *Dasyatis pastinaca* (Linnaeus 1758)

The common stingray is a demersal species distributed along all the coast of Europe from Norway including the Baltic and the Mediterranean Seas and reaching the Black Sea. It feeds predominantly on crustaceans and small fish and molluscs. The species is not targeted by fisheries but is often taken as bycatch by trawls and usually discarded. There is not enough data to assess the status of the species, although is thought to be Near Threatened.

Cuckoo Ray — *Leucoraja naevus* (Müller and Hanle, 1841)

This demersal species is widely distributed on soft substrates such as sand and mud in the range of 20 to 500 m depth. Juveniles prey mostly on small crustaceans and polychaetes while adults prey on bony fish. Compared to most rays, this one is small with high fecundity, making it less vulnerable to fishing pressure. It is not a fisheries

targeted species, although is an important by-catch of multispecies trawl fisheries. The Red List status for this species is Least Concern.

2.10.6 Angling

Sea fishing within and around the Humber REC area is carried out from a beach, shore, pier, jetty and from a boat. Recreational fishing within the Humber estuary and REC area include fishing for species such as sea bass, mackerel, mullet, flounder, plaice, dogfish and rays. Many anglers in the region take part in a UK wide elasmobranch (sharks and rays) tagging programme set up by the National Oceanography Centre in Southampton. The common smooth hound (*Mustelus mustelus*), starry smooth hound (*Mustelus asterias*), blue sharks (*Prionace glauca*), porbeagles (*Lamna nasus*) and mako sharks (*Isurus oxyrinchus*) are all targeted in the study. There are many commercial sea angling boats which can be chartered along the east coast and Humber region and sea-angling is a very popular pastime.

2.11 Aggregates

In both England and Wales, marine aggregates are an important source of sand and gravel, accounting for about 21% of total supply (Highley *et al.*, 2007). The total marine aggregate production in 2008 was 21.24 million tonnes (Mt). Most marine sand and gravel is used in the manufacture of concrete and general building works. In recent years significant quantities of marine dredged sand have also been used for beach nourishment schemes which involve the pumping of large volumes of sand onto beaches to reinforce the natural defences of the coastline.

At present there are 79 aggregate production licences on the continental shelf off the coastline of England and Wales. The majority of these licenced areas are offshore of the South and East coast of England but they are also located in the Bristol Channel and Irish Sea. Within these areas there are seven main offshore regions where dredging takes place, of which the Humber area is one. (The Humber Region in this aggregates section refers to the Region as defined by The Crown Estate in their aggregate statistics www.thecrownestate.co.uk/dredge_areas_statistics).

In the Humber REC area there are at present a total of twelve licenced dredging areas with dredging taking place in nine of these,

by four active operating companies (Figure 2.11.1). In 2008 the total licenced area in the Humber was 454.62 km². The presently licenced areas are mainly in the west; west of Silver Pit, with a cluster around the Dowsing Bank and one in the vicinity of Sole Pit, in the east. At present a further 10 licence applications have been lodged (Figure 2.11.1), that are currently in the process of evaluation.

37.327 Mt of aggregate was dredged from the Humber REC area between 1998 and 2007 (The Crown Estate & British Marine Aggregate Producers Association BMAPA, 2009a). The cumulative footprint of dredging during this ten-year period covered 103.3 km² of the sea bed which is ~1% of the 10 835 km² area encompassed by the Humber REC study area. Averaged across the cumulative footprint, this volume of material represents 21.7 cm of sediment depth removed across the whole area dredged. In 2008, 3.6 Mt of material was dredged from the area (The Crown Estate & British Marine Aggregate Producers Association BMAPA, 2009b). Of this tonnage 3.15 Mt was used in construction and 0.45 Mt in beach nourishment. Of the total marine aggregate dredged for construction, 1.02 million tonnes were landed at wharves in the North East, located on the Tyne, Tees and Humber rivers. Some 0.10 million tonnes were landed elsewhere in England and 2.03 million tonnes were landed at wharves in mainland Europe (The Crown Estate & British Marine Aggregate Producers Association BMAPA, 2009b).

The main reason for the strong interest in dredging in the Humber area is the large area of coarse-grained sediment in the western part of the region. There is a thin, centimetres thick, mobile sediment cover (Figure 2.3.4) that covers large areas of the sea bed, but this is mainly sand. This fine-grained cover is underlain by coarse-grained relict, sandy gravel that is mainly less than a metre thick (Harrison *et al.*, 1998) that overlies till. It is the gravel that is the primary objective of the dredging companies. Although over most of the area the coarse-grained sediment is thinly developed, there are thicker sediments developed as banks. In addition, there is a complex network of glacially formed channels incised into the Bolders Bank Formation. These channels have various infills some of which are fine-grained, but others also coarse-grained. This coarse-grained sediment may contain significant resources of aggregate (Harrison, 1992). In addition, the Bolders Bank

Till is in places formed of sand/gravel beds as well as having a significant component of coarse-grained sediment (including gravel and boulders). These too may be a source of aggregate. Farther offshore in the Inner and Outer Dowsing areas the active dredging licences are located on sand waves and banks.

The impact of dredging on the marine biota is mainly on benthic and epibenthic organisms. The process of extraction typically results in a series of tracks 2–3 m wide and around 50 cm deep (van Moorsel and Waardenburg, 1990; Kenny and Rees, 1996; Boyd *et al.*, 2002) although deeper troughs result where the drag head crosses the same area a number of times. In all cases removal of sediment from the seabed kills the benthic and epibenthic biotas.

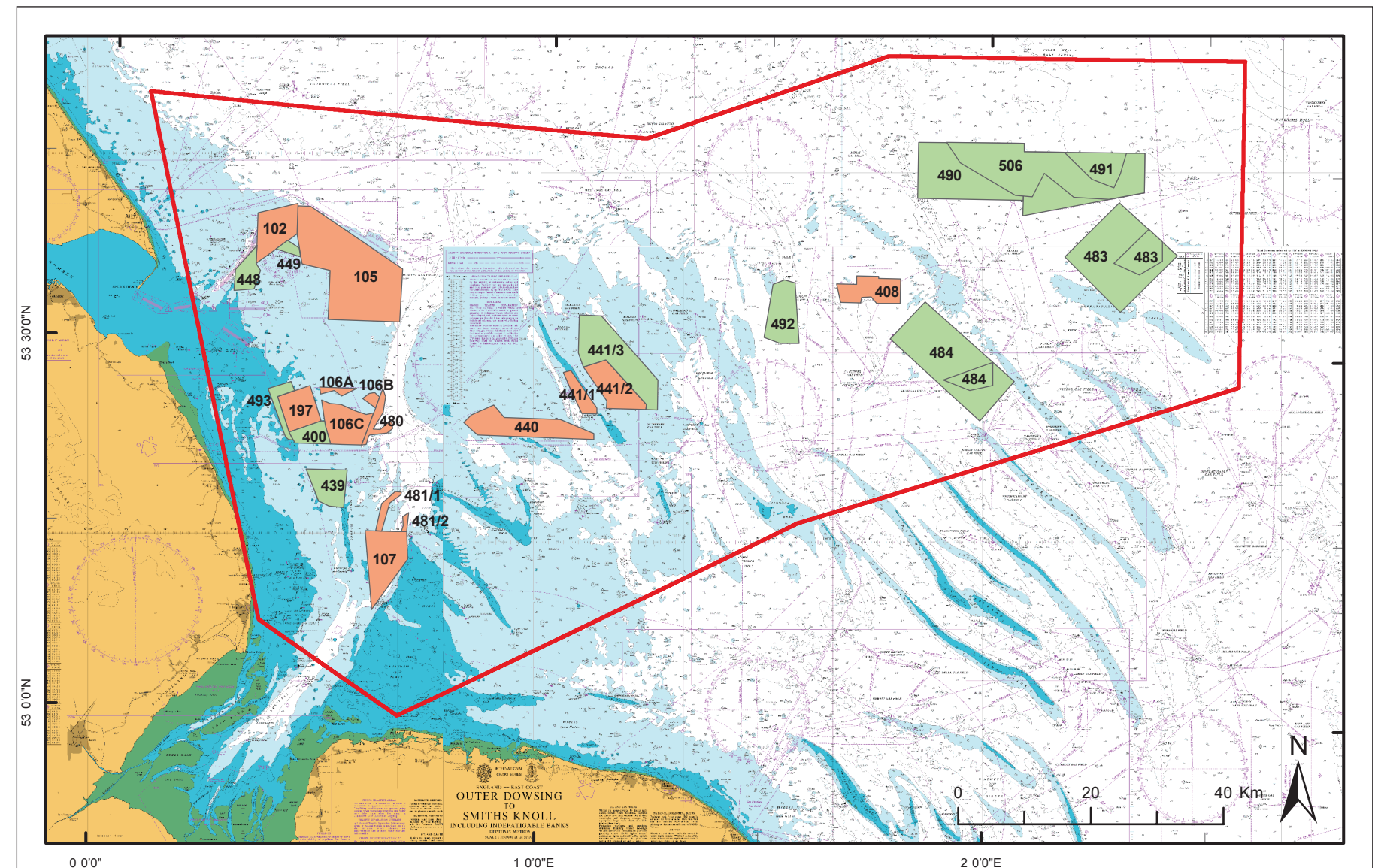
The total depth of sediment removal depends on the intensity and frequency of dredging activity as well as the active sedimentary processes operating in the area that may or may not result in replacement of the sediment removed. Over the long term, where removed sediment is not replaced by natural processes, the depth of the seafloor may be reduced by a number of metres. This can result in replacement of coarse-grained by finer-grained sediment, a process further enhanced by the settlement of (finer-grained) sand released during the dredging operation. Fine-grained sediments are naturally released with water from the dredging vessel in the overflow but are also released during the screening process. Screening is carried out where the sand:gravel ratio needs to be adjusted to suit customer requirements. It results in significant quantities of sand being rejected and returned to the seabed.

2.12 Offshore Wind Farms

The UK Governments recent drive for the development of renewable energy sources has led to the Humber region being identified as an area having considerable potential for wind energy. The Humber REC area is located within Greater Wash Strategic Area that in 2002 was identified as a prime location for offshore wind farm development. Planning applications for The Inner Dowsing and Lynn wind farms that were approved under Round 1 of the UK offshore wind development strategy, have been constructed and are now operational (Figure 2.12.1). Sheringham Shoal is under construction. All the other wind farms are at various stages of planning.

- Humber REC Study Area
- Application Dredging Areas
- Licenced Dredging Areas

Figure 2.11.1: Aggregate licenced areas and aggregate licences applied for (October, 2010).
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In December 2003, under Round 2 of the development strategy eight further sites were approved. The tender provisions for Round 2 developments outline the main criteria for the new projects and recognize four size categories (The Crown Estate, 2003).

- Extensions to Round 1 projects - <5 km²
- Small Project - >5 to <35 km²
- Medium Project - >35 to <75 km²
- Large Project - >75 to <250 km²

Comparisons between Round 1 and Round 2 lease requirements reveal significant differences in the constraints on location, the number of turbines and turbine size (Table 2.12.1). Round 2 projects are generally much larger than those of Round 1. Development is located further offshore and occupying locations closer together. All the leases are in shallow water and mainly in areas of sand banks.

Individual Round 2 projects have a capacity of between 64 and 1 200 MW. At the beginning of Round 2, 2 MW turbine output was considered cutting edge, but now the technology has advanced with 3.6 MW turbines commonplace. Today, most developers

intend to install 5 MW turbines, or more, in the larger scale Round 2 developments. Overall, across the 15 projects planned on the UK shelf, the number of turbines for each site averages out at around 100, with the largest scheme potentially having approximately 240 turbines. This compares to a maximum of 30 turbines permitted under the Round 1 developments.

In addition, the larger capacity turbines of the Round 2 installations are powered by larger blades with larger swept diameters at greater hub heights. Consequently, the engineering structures (towers and foundations) to support the larger devices are larger than those of Round 1, with a larger separation between adjacent

Round 1	Round 2
No minimum distance from coast	Coastal exclusion zone to provide a buffer of between 8 to 13km from the coast
Schemes restricted to Territorial Waters	No lease restriction to Territorial Waters
Lease areas limited to 10km ²	Lease areas limited to 250km ²
Maximum of 30 turbines per lease	No restriction on number of turbines
Lease sites dispersed around England and Wales	Lease sites restricted to 3 strategic areas
Minimum installed capacity of 20MW	Minimum applied capacity of 64MW Maximum applied capacity of 1,200MW

Table 2.12.1: Comparison of Rounds I and II wind farm lease condition (Kenyon and Cooper, 2005).

turbines. Under Round 1, the majority of installations had mono-pile foundations with diameters of ~5 m, and separations of around 400 to 600 m. In Round 2, larger diameter mono-piles are of around 6 m. In consideration of increased blade diameters, Round 2 arrays have larger turbine separations, probably in the region of 800 to 1000 m.

Further progress on developing the UK's resources in alternative energy came in December 2007, when John Hutton, then Secretary of State for Business Enterprise and Regulatory Reform (now the UK Department of Business, Innovation and Skills) announced the commencement of a Strategic Environmental Assessment (SEA) to examine 25 GW (gigawatts) of additional UK offshore wind energy generation capacity by 2020. This follows the 8 GW planned for Rounds 1 and 2. The EU target, to produce 20 percent of Europe's energy from renewable sources will come significantly from wind energy.

The UK offshore area has a significant potential in offshore wind power; thus additional wind farm development is planned. However, the scale of delivering the potential energy is far larger than in Rounds 1 and 2. Delivery of the capacity required in Round 3 requires a massive investment in both onshore and offshore energy infrastructure and supply chains. Thus, in 2008, The Crown Estate announced a third Round of offshore wind farm leasing (<http://www.thecrownestate.co.uk/round3>). Within

this process, The Crown Estate is taking a more prominent role, where it will co-invest with developers, combining the technical experience of the offshore wind industry with efficiencies generated by The Crown Estate's access to resources and stakeholders. The Round 3 sites are far larger than those of Rounds 1 and 2. To the north of the Humber REC area the Dogger Bank site (8,660km²) has the potential to become the world's largest offshore wind farm, generating up to 13GW which is estimated to be 10 percent of the projected UK energy requirement. Impinging on the northeast corner of the Humber REC area the Hornsea site (4,735km²), (Figure 2.12.1) is planned to produce up to 4GW of power.

As with the removal of aggregate in dredging, wind farm construction has the potential to cause 'beach draw-down', where sediments from the upper beach move down to fill a dredged depression. However, as Round 2 construction is very much offshore, this is not considered to be a problem. Wind farms on sand banks outside of the coastal exclusion zone will neither create sizeable depressions or are far enough offshore not to cause drawdown (Kenyon and Cooper, 2005). Hallermeier (1977) provides a depth of closure hypothesis to quantify this depth limit based on criteria of wave height, period and sediment density.

Generic research into the potential environmental impact of offshore wind farm development on coastal processes suggests that the main effects are most likely confined to individual turbine foundations, and manifested as 'local' scour (Kenyon and Cooper, 2005) As long as a large spacing between adjacent turbine blades is maintained (based on a distance that optimizes wind energy capture) and the relative scale of individual foundations remains small, the potential for 'global' (cumulative) scour should be removed. If, however, 'global' scour takes place the equilibrium conditions of a sand bank are likely to be altered.

The environmental impacts of offshore wind farm development on seabed biota are very similar to those associated with aggregate extraction. The impacts of both construction and decommissioning of wind towers on the seabed include: increased levels of suspended sediment, settlement of suspended sediments, scour associated with the presence of the turbine structures, together with noise and vibrations during engineering operations. The impacts also extend along the associated cable routes constructed

between the wind farms and the coast. The result is habitat disturbance and loss.

Offshore wind farm development is in its infancy in the UK. Thus our understanding of the environmental impact of offshore wind farm construction and operation is at a very early stage. For the most part, it is based on the impacts from aggregate extraction and construction of offshore oil and gas infrastructure such as production facilities and pipelines. The environmental impact of the two wind farms currently operating in the Humber region is considered to be limited. However, with the prospect of construction of a further, much larger, developments this situation may change. It is likely that the environmental impact of these larger developments will be greater than those building under Round 1. An additional aspect is that the wind farm construction is in the same locality as most of the dredging activity, in the west of the Humber REC area. Thus the cumulative impact of both dredging and wind farms will be significant.

Web Links:

The Crown Estate - <http://www.thecrownestate.co.uk/round3>

Renewable UK (Formerly the BritishWind Energy Association - <http://www.bwea.com/offshore/index.html>)

2.13 Oil & Gas Development

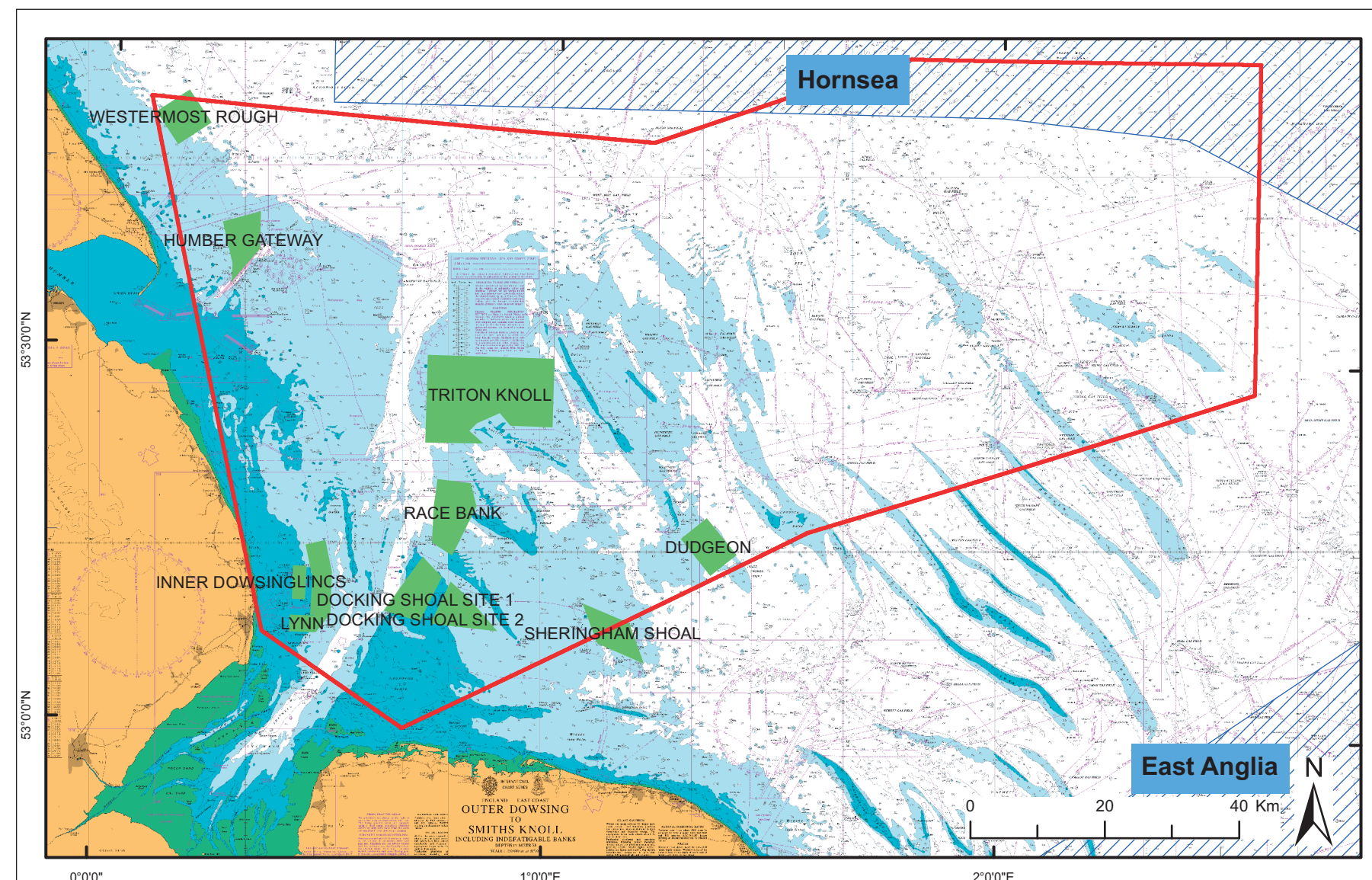
Since the discovery of significant reserves in the 1960's, the North Sea has become a key area of oil and gas production in the UK. The reserves are limited compared to those in the Middle East, but they have had a major impact on the UK economy. UK production peaked in the 1990's since when there has been a steady decline. The southern North Sea mainly produces gas. The infrastructure developed for its exploitation (Figure 2.13.1), especially the offshore production platforms, are a significant part of the offshore landscape in the Humber region (Hagland, 2000). As the gas in the area has gradually been depleted, alternative uses for the reservoirs have been developed. For example the Rough field reservoir is now utilised for gas storage.

The construction of seabed well heads, production platforms and pipelines, and their continuing presence, have all had an environmental impact on the seabed biological communities.

- Humber REC Study Area**
- Humber REC Study Area
 - R3_Windfarm_zones
 - Round_1&2_Windfarms

Figure 2.12.1: Windfarm licenced areas.

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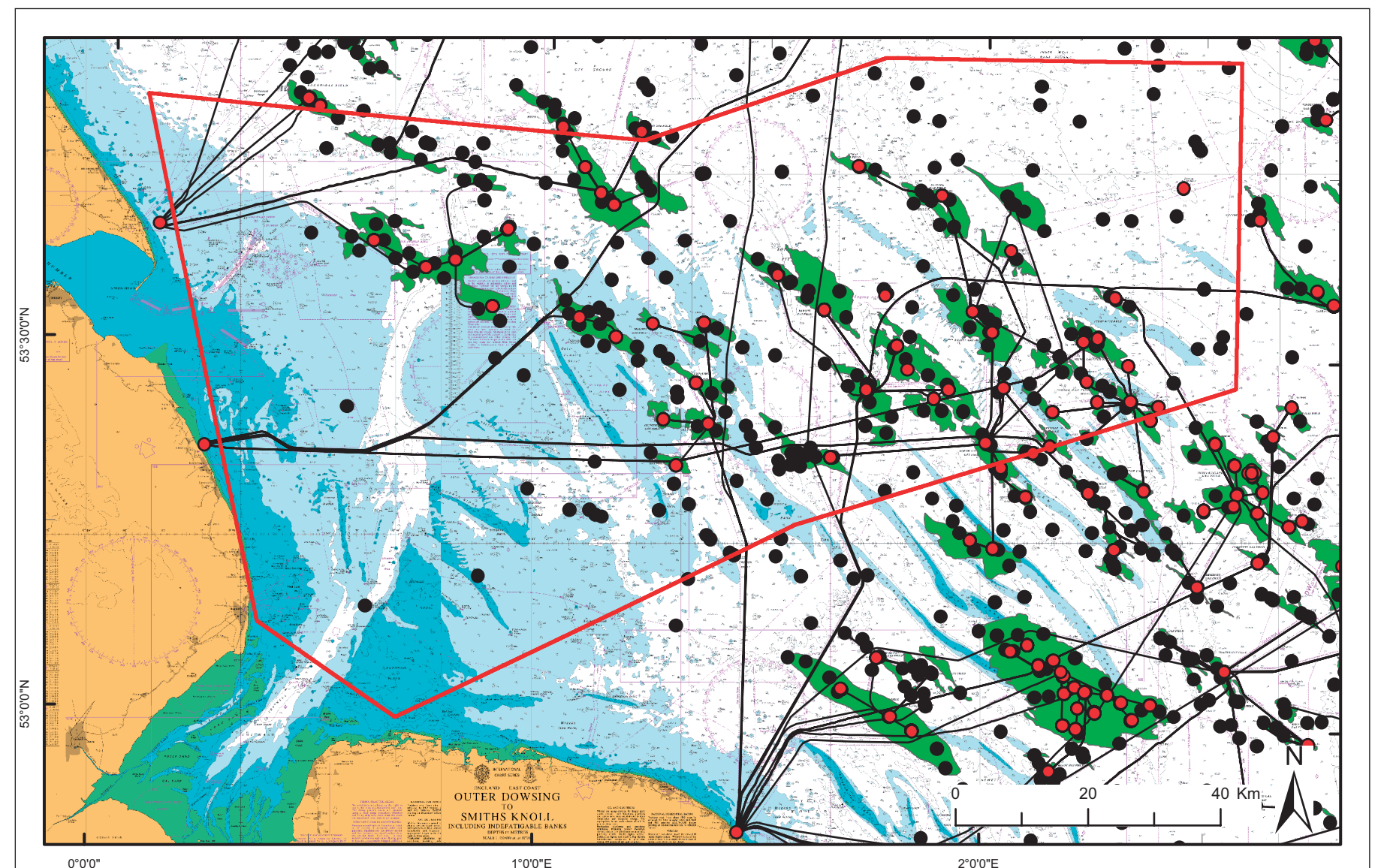
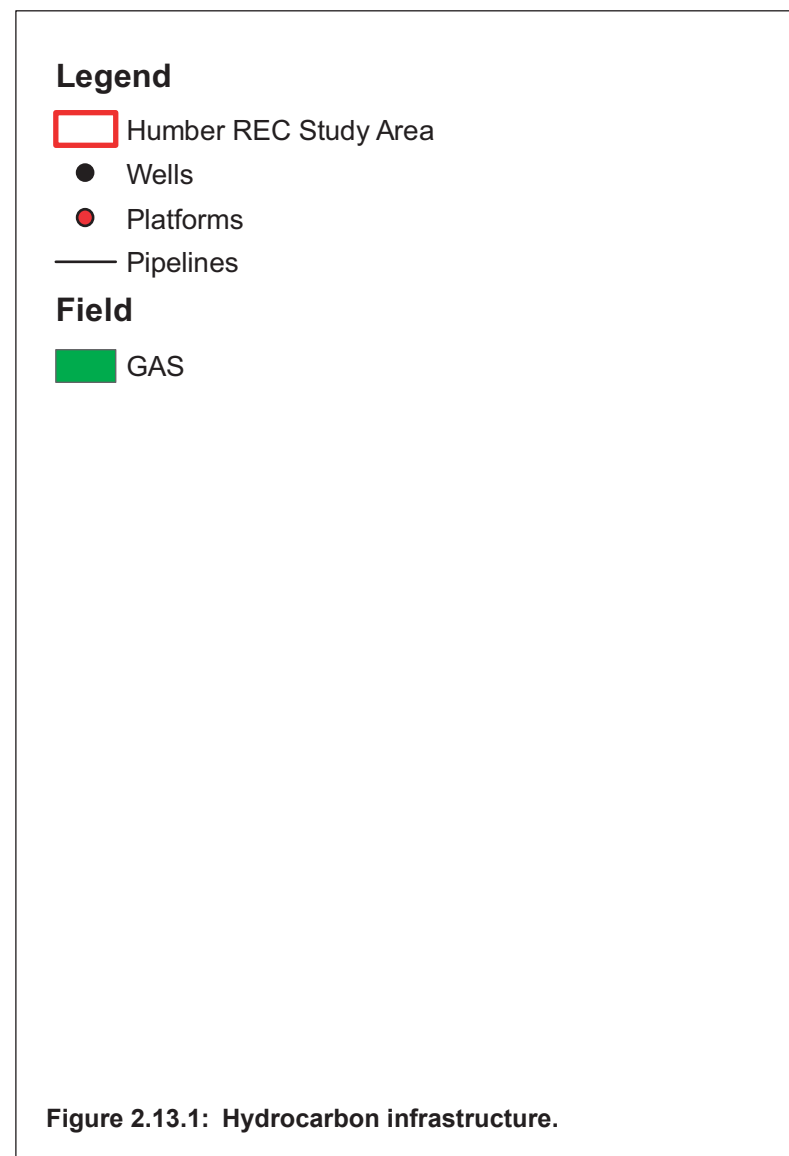
Main impacts are similar to those in aggregate extraction and wind farm construction and include sediment removal and smothering as well as noise and vibrations from the platforms themselves during their operation. Another, although limited form of impact from the oil and gas industry is from drilling activity.

The drilling removes rock from the sub-seabed and returns this as chips, termed 'cuttings', to the surface where they are sampled and described before being dumped back into the sea. Drilling operations require lubrication by viscous drilling mud, and these too are traditionally discharged into the sea. Water based mud (WBM) released into the water column becomes separated from the cuttings and is diluted, and rock particles in

the water column are unlikely to be distinguishable from natural suspended solids.

In the relatively shallow and dispersive waters of the southern North Sea it is generally accepted that cuttings do not accumulate at the well site but are transported away from the platform and dispersed naturally. The most common effect of the WBM is an elevation of barium concentrations in the sediments, which may extend up to 1 000 m from the drilling location along the predominant tidal axis. Barium persists in sediments, in the form of barium sulphate or carbonate, which are insoluble and therefore inert.

The presence of drilling and production of oil and gas may result in an accidental release of oil, condensate or gas that, depending on the scale, the characteristics of the hydrocarbon, the prevailing weather conditions and the proximity of sensitive populations, may result in damage to the marine environment. Condensate has low viscosity, so when spilt at sea spreads rapidly and disperses. The accidental release of oil presents a greater risk, particularly in the event of an oil well blow-out in which the hydrocarbons cannot be contained. In the southern North Sea the main hydrocarbon is gas, which upon violent release may have a serious impact on local facilities such as platforms or ships but, would have no long term environmental impact. On the broader scale, there have been no



such incidents during drilling activity in the southern North Sea to date.

Web links:

<https://www.og.decc.gov.uk/>

2.14 Tidal Power

To the west of the Humber REC region, in the Humber estuary, there is a demonstration tidal energy unit. The technology was locally developed and utilises horizontal blades which move in the tidal stream and drive a generator. It is located off Immingham and

became operational in July 2009. Working at full capacity, the unit produces a total of 100 kilowatts of electricity — enough to power about 70 homes. But, the power is being fed directly to Immingham chemical company Millennium Inorganic Chemicals (MIC), making it the first business in the UK to take a direct electricity feed from tidal power. A new larger capacity unit is planned to be installed in 2011 at Sammy's Point. This system should be able to generate at least 1 000 megawatts and potentially meet the energy needs of more than 500 homes.

3 Project Planning, Survey Data and GIS

The Humber REC was envisaged and carried out as a unified, integrated scientific project, subdivided sequentially into five main activities:

1. A Desk-Based Report (DBR)—providing an initial review of the existing state of environmental knowledge within the Humber REC project area,
2. A regional marine geophysical survey acquiring; single-beam and multibeam echo sounder, sidescan sonar, high-resolution sub-bottom seismic (using sub-tow and surface Boomers) and magnetic data,
3. A marine sampling (Ground Truth) survey including; vibrocoring, grab sediment sampling (bulk and biological), seabed imagery (video and stills photography) and seabed trawling,
4. Processing of the environmental data—including Particle Size Determination, compiling faunal lists, seabed photography and vibrocores, and
5. Final reporting—based on the interpretation and integration of all the above data.

The DBR was completed in late 2008 and was followed, during the autumn and winter of 2008/09, by the geophysical data acquisition. Based on a preliminary interpretation of the geophysical data the seabed sampling took place in April 2009. Processing of the sample data was completed by the end of summer 2010 and interpretation and report writing followed. The DBR was a confidential report to the MALSF, but the main results are synthesised in Chapter 2—Regional Perspective. The original survey data together with the processed environmental data is freely available and can be accessed at: www.marinealsf.org.uk. This publication covers the final reporting and can be freely downloaded from: <http://www.alsf-mepf.org.uk/>.

In this section we address the planning and organisation of the two marine surveys and identify the data available on the GIS and how this may be accessed.

3.1 Geophysical Survey Strategy and Acquisition Methods

For the Humber REC the geophysical survey strategy was less prescriptive than that of previous RECs, Eastern English Channel Marine Habitat Map (EECMHM) (James *et al.* 2007), the South Coast REC (James *et al.* 2010) and the Thames Estuary (Emu Ltd, 2009). On these surveys, sidescan sonar and multibeam echo sounder (MBES) were deployed simultaneously along each of three adjacent survey lines with the aim of providing a sea bed swath width of up to 500 m (depending on water depth) for each corridor. Shallow sub-sea bed (Boomer) seismic data was simultaneously acquired only along the centre line of each corridor. For the Humber the approach was to devise a survey strategy that reflected the natural environment of the region in the context of the financial resources available.

The objectives of the geophysical survey were to obtain; i) a regional grid of data that would broadly characterise the Humber REC area from the perspective of geology, archaeology and biology, and ii) obtain within small, focussed, survey areas a data set with a high line density that addressed issues specific to the archaeology and biology. The regional grid of lines was planned to capture the full diversity of geological, biological and archaeological environments identified in the DBR.

Survey planning took account of the significant fishing activity in the area as well as seabed construction associated with wind farm and gas field infrastructure. A major objective was to avoid conflict with these. The shellfish industry off of the east coast of the Humber deploys long lines (kilometres in length) of static gear (pots) deployed over large areas of the seabed. This static gear poses a significant hazard to geophysical equipment towed at shallow depth, as does the equipment to the pot lines. Because of the large tidal range in the Humber area the buoys locating the pot lines may be submerged at high tide, thus at times they are not visible. Previous to the survey, to address the issue, meetings were arranged by the National Federation of Fisheries Organisations (NFFO) with local fishermen. Additionally, a full time Fishing Liaison Officer (FLO) was employed onboard the survey vessel to provide liaison with local fishermen and advise the survey vessel of potential hazards. On occasion, when surveying in areas of high density activity a scout vessel was deployed. These mitigation

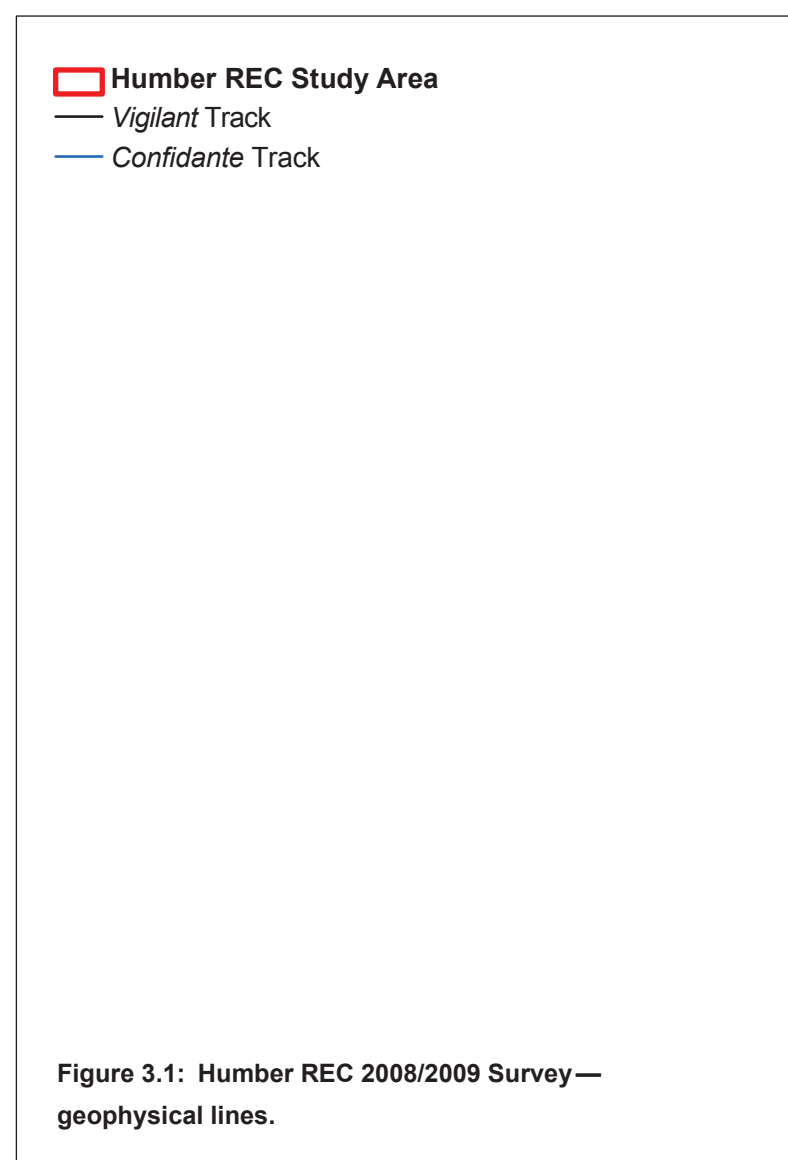
measures proved to be very successful. There were no incidents and cordial relations with fishermen were maintained.

Due to the very shallow inshore waters, two survey vessels were required to acquire the geophysical data. The first survey was in deep waters aboard the MV *Vigilant*. Mobilisation was on the 16th October 2008, but because of bad weather, the survey was terminated on the 17th November before acquisition of all the data. The vessel remobilised on the 20th January 2009 and completed surveying on the 17th February. The shallow-water survey took place on the MV *Confidante* between the 27th February and 19th March.

Initially 4500 line kilometres of data were to be acquired, but because of the adverse weather conditions this was reduced to 3000 km. Overall, the survey suffered from 57% weather down time. Most of the data from the two deep water legs is fit for purpose, but some data shows the effects of the marginal weather conditions that often prevailed. The shallow-water data was acquired in better weather conditions and is of better quality.

In the deep- water area, approximately 2500 line km of data were acquired along 18 Corridors, each comprised of two parallel survey lines, 100 to 150 m apart (Figure 3.1). 16 Corridors were orientated approximately NW to NNW, with two tie lines oriented approximately EW. These orientations were chosen primarily for two reasons:

- The NW/NNW survey line orientation generally lies parallel with maximum tidal vectors. Running with the tides improves ship handling and perhaps more importantly, improves positioning accuracy of the towed geophysical equipment. The line spacing between the NW-NNW oriented Corridors is approximately 10 km,
- The survey lines parallel the primary orientation of the large-scale seabed morphology, e.g. tidal sand ridges and deeps. Surveying parallel to these bathymetric highs improves imaging quality as it reduces the need for instrument adjustments to sudden and extreme changes in relief. Surveying normal to these features would require constant instrument adjustment to the sudden and extreme changes in relief, introducing unnecessary noise to the data and increasing processing time.



Data on the shallow-water survey was acquired along 13 survey lines. Line orientation was in part determined by seabed morphology although there were also limitations due to the tides and the necessity to avoid fishing gear. This resulted in a greater deviation from the NNW–NW orientation of the deep-water lines, although this orientation was generally followed. 500 line km of data were acquired with a line spacing of approximately 10 km. Because of time constraints data was acquired along only one line, so the Corridor approach of the deep-water survey did not take place.

3.1.1 Focussed Surveys

In addition to the regional lines, four areas were identified for detailed survey; two for biology: Bio 1 and Bio 2 (Silver and Sole pits) and two for archaeology: Arch Area 1 and Arch Area 2 (Silver Pit and northeast Humber) (Figure 3.1). The line spacing in these areas was between 100 and 200 m.

Biology

Two areas were identified for detailed biological study because of their potential to support species and habitats of conservation importance.

The Silver and Sole pits are the largest of the deeps within the Humber REC area. High abundances of *Sabellaria spinulosa* and the pink shrimp *Pandalus montagui* have long been associated with the Silver Pit although it has never been studied in any detail. *Sabellaria spinulosa* is a tubicolous polychaete and the reef structures which it builds from sand are protected under Annex I of the EC Habitats Directive. The presence of *S. spinulosa* reefs along the Silver Pit could qualify the area for designation as a Special Area of Conservation (SAC) although records of the reef associated with this feature have, until now, been incidental and spatially disparate. The aim of the detailed biological survey

of the Silver Pit was to investigate the environmental conditions most suited to the development of *S. spinulosa* reef across this deep and to look in detail at the ecology of the reefs which exist here.

The biological communities associated with the Sole Pit have not been studied at all in the past, in part because this feature lies well away from any offshore developments. This area was included in the targeted biological study in order to ascertain the differences and commonalities between the two deeps and the biological communities which they support. Because the two deeps are very large it was not possible to map them in their entirety so smaller, representative, cross-sections were identified for study.

Archaeology

Initial investigations of seabed prehistory highlighted several key areas which would significantly add to the scientific understanding of the region and the archaeological resource. Of these areas, two were selected for detailed survey; one located in the northeast of the region (Arch Area 1), the other on the eastern margin of the Inner Silver Pit (Arch Area 2).

Arch Area 1 was chosen because of its potential to significantly advance our archaeological understanding of the area. The survey grid was positioned over a large prehistoric channel recorded in part for the first time by the ALSF funded 'North Sea Palaeolandscapes Project' (NSPP). Significantly the channel does not have expression in the SeaZone bathymetric data and is therefore not currently visible on the seabed surface. The palaeochannel and floodplain is a maximum of 500 m wide and represents one of the significant drainage channel features within the archaeological landscape of this region if not the British Isles during the Mesolithic. In addition since the channel has been observed to connect to the palaeocoastline of this region, it is likely to have represented a major route way for human movements within this area.

Arch Area 2 was proposed to cover the correspondence of physical features located on both the NSPP database and a feature with bathymetric expression in the SeaZone Bathymetry. Due to data striping in this region of the NSPP database the resolution of this feature was poor. However it was thought to be related to the Late Palaeolithic to Earliest Mesolithic landscape. Given this features

differing morphology and surface expression, as well as its poor resolution within the pre-existing archive, the decision was taken to select this feature for detailed survey.

3.1.2 Geophysical Equipment

Details of the geophysical equipment used on the survey are to be found in the acquisition report; Gardline Environmental, 2009. Humber Regional Environmental Characterisation Project — Geophysical Survey Operations Report: October 2008 — March 2009, at <http://www.alsf-mepf.org.uk/>. Below we provide brief details of the equipment used.

Multibeam Echo Sounder (MBES)

On the MV *Vigilant*, the MBES was a Kongsberg Simrad EM 710, mounted on the keel. The instrument is a 1° x 1° system operating at 95 kHz frequency; with 256 beams and a swathe footprint of approximately 3 times the water depth. On the MV *Confidante*, a Kongsberg Simrad EM3002D MBES was deployed. The system was operated at 300 kHz, with 508 beams with a seabed swathe width of approximately 5 times the water depth. On both surveys, vessel speeds of 4 knots over the ground were typical.

All soundings were reduced to Lowest Astronomical Tide Datum using predicted tidal ranges from the standard ports of Immingham and Cromer. The ranges at these ports were extrapolated to the site using Admiralty Co-tidal Chart 5058 (edition 5–1996). The reduced water depths in the survey area were calculated using Gardline's proprietary Tidesol software.

CARIS HIPS software was used to process the multibeam data in order to provide raw and processed bathymetry depths. All data was viewed and cleaned to remove outliers from both positions and depths. Statistical analyses of the data ensured the quality control of the dataset. As part of this process, data from the central MBES beams were compared against single beam echo sounder profiles. The bathymetry data is provided as generic sensor format (*.gsf) of all accepted soundings together with ASCII XYZ (*.txt) data gridded at a 1m bin size. The data is also provided as a seabed digital terrain model (DTM) at a scale of 1:200 000 and as geotiffs of seabed relief at a resolution of 1m and 2 m. Backscatter geotiffs are provided at a resolution of 1 m.

Single Beam Echo Sounder

Single-beam bathymetry data was acquired on both survey vessels using a hull-mounted, Kongsberg Simrad EA 400 echo sounder, recording at frequencies of 38 and 200 kHz. The data were heavily compensated by motion reference units and used to monitor the calibration of the multibeam swathe echo sounder. The 200 kHz data were recorded digitally as were all echo sounder returns.

Sidescan Sonar (SSS)

An Edgetech, dual frequency (100 and 420 kHz), 4200 sidescan sonar was deployed from both survey vessels with data acquired at both frequencies. Data were displayed on paper records and digitally recorded in .xtf format across a range of up to 200 m for the low frequency and 125 m for the high frequency. Data could be collected in either High Definition (HD) or High Speed (HS) mode. HD yields better data, but only in ideal weather conditions. Thus HS mode was predominantly used on main corridor lines and HD mode was used in the detailed biological survey areas. Sonar 'fish' layback varied (10–200 m) depending on the water depth. Data were post-processed using Coda software to produce geotiffs. Data were displayed on paper records and provided as *.cod files

On the MV *Vigilant* the towfish position was monitored by a Sonardyne Ranger ultra short baseline acoustic (USBL) system. Based upon the USBL configuration and slant range observations, the USBL system provided fish tracking positions with an estimated positioning error of ±10 m. On the MV *Confidante* the USBL system was not used because of the danger of damage to the tracking head in the shallow water.

Data quality were assessed real-time by Gardline engineers and QA'd regularly by Gardline Geophysics staff, and onboard BGS and Wessex Archaeology geophysicists to determine if line re-runs were necessary.

Sub-bottom Profiler—Boomer

A sub-tow boomer was deployed for sub-bottom profiling on the MV *Vigilant* and surface tow boomer on the MV *Confidante*. The Boomer data was acquired to image the sub-seabed geology up to depth of ~40 m, depending on the sediment and rock type.

The source 'bang box' was typically run at an energy level/firing rate of 300 joules/350 milliseconds aboard the MV *Vigilant* and 200

joules/250milliseconds aboard the MV *Confidante*. Data acquisition and initial processing utilized Coda Octopus 760. The data were band pass filtered between 1 and 4.5 or 8.4 kHz and displayed with an 80 or 100 millisecond sweep. Ship 'noise' aboard the MV *Vigilant* required that the ship's engine revolutions and propeller pitch were 'tuned' to avoid interference with the boomer signal. Data were displayed on paper records and are provided as *.cod files.

Data quality were assessed real-time by Gardline engineers and QA'd regularly by Gardline geophysics staff, and onboard BGS and Wessex Archaeology geophysicists to determine if line re-runs were necessary. For interpretation, data were post-processed using Coda.

Magnetometer

A Geometric G882 magnetometer was used on all surveys to identify ferrous metal on or below the seabed e.g. wrecks, pipelines, etc. The system has a sensitivity of 0.02nT. Data were recorded on the navigation computer system at a rate of 1 Hz. The sensor was towed on a dedicated cable at a fixed distance of 100 m astern of the MV *Vigilant* and 60 m astern of the MV *Confidante*.

3.2 Ground Truth Sampling Survey

The sampling survey took place during April-May 2009 on the MV *Sea Profiler* (Figure 3.2). The sampling plan was based on the DBR and preliminary archaeological, geological, and biological interpretations of the data acquired during the geophysical survey. The objective of the Survey was to occupy the maximum number of sample sites that would represent the sediment distribution and the biological diversity of the Humber REC area and that was feasible within the finance available. In addition to the geological and biological objectives, a number of sites were identified for sediment coring of archaeological objectives. The survey was divided into two Legs:

- Leg 1 (Geotechnical)—of ten days duration, to acquire 90 large-volume (Clamshell) grab samples for Particle Size Determination, and a maximum of 49 sediment vibrocore sites to ground-truth the geophysical data and contribute to the archaeological palaeoenvironmental interpretation, and

- Leg 2 (Environmental) — of 15 days duration, and initially planned to acquire seabed imagery (video and still photography), sediment grab samples at 90 locations and seabed trawls at 30 sites; these samples were to ground-truth the geophysical data and contribute to the overall biological interpretation in supporting the interpretation and delineation of infaunal and epifaunal communities.

However, after consideration of the DBR, the REC geophysics, the size of the area and the varied seabed environment, it was agreed that, as a contingency, an additional 50 sites would be occupied for sediment grab samples and seabed imagery if time allowed. Permission from Natural England was applied for, and granted, to operate the Hamon grab and the 2 m scientific trawl on possible biogenic reef areas.

The broad scale sampling programme was based on the following criteria (and assuming the specified level of sampling);

- Intersections of the geophysical lines were targeted as a first priority as these provide the best geophysical data for example side-scan sonar data collected from opposing directions,
- End of line points were also sampled to ensure the greatest geographic spread of stations across the area,
- The BGS seabed sediment map showing Folk classification was utilised to ensure adequate sampling in each of the main sediment types/habitats,
- Proportionally more sampling stations were located in the inshore region as this area was identified as being more heterogeneous both in terms of the geology and the biology,
- The inshore area also has the highest concentration of anthropogenic activity, both present and planned,
- Clamshell grab sample locations were further adjusted following preliminary analysis of the multibeam bathymetry and backscatter data, with the intention of sampling distinctive sediment and bed form types,
- Hamon grab sample locations were further adjusted following preliminary analysis of the sidescan sonar data and the identification of areas with potential biogenic structures e.g. mollusc beds and *Sabellaria* reefs.

In the focussed survey areas for archaeology, locations were identified on palaeo-river channels. For biology, six sampling stations were located in each of the two targeted biological areas in the Silver and Sole pits, with a further eight sites reserved for sampling interesting features identified from the sidescan sonar. Figure 3.2 shows the location of the samples acquired.

On both Legs a FLO was again employed to liaise with local fishermen and, again, there were no incidents involving fishermen or static gear.

3.2.1 Equipment Deployed

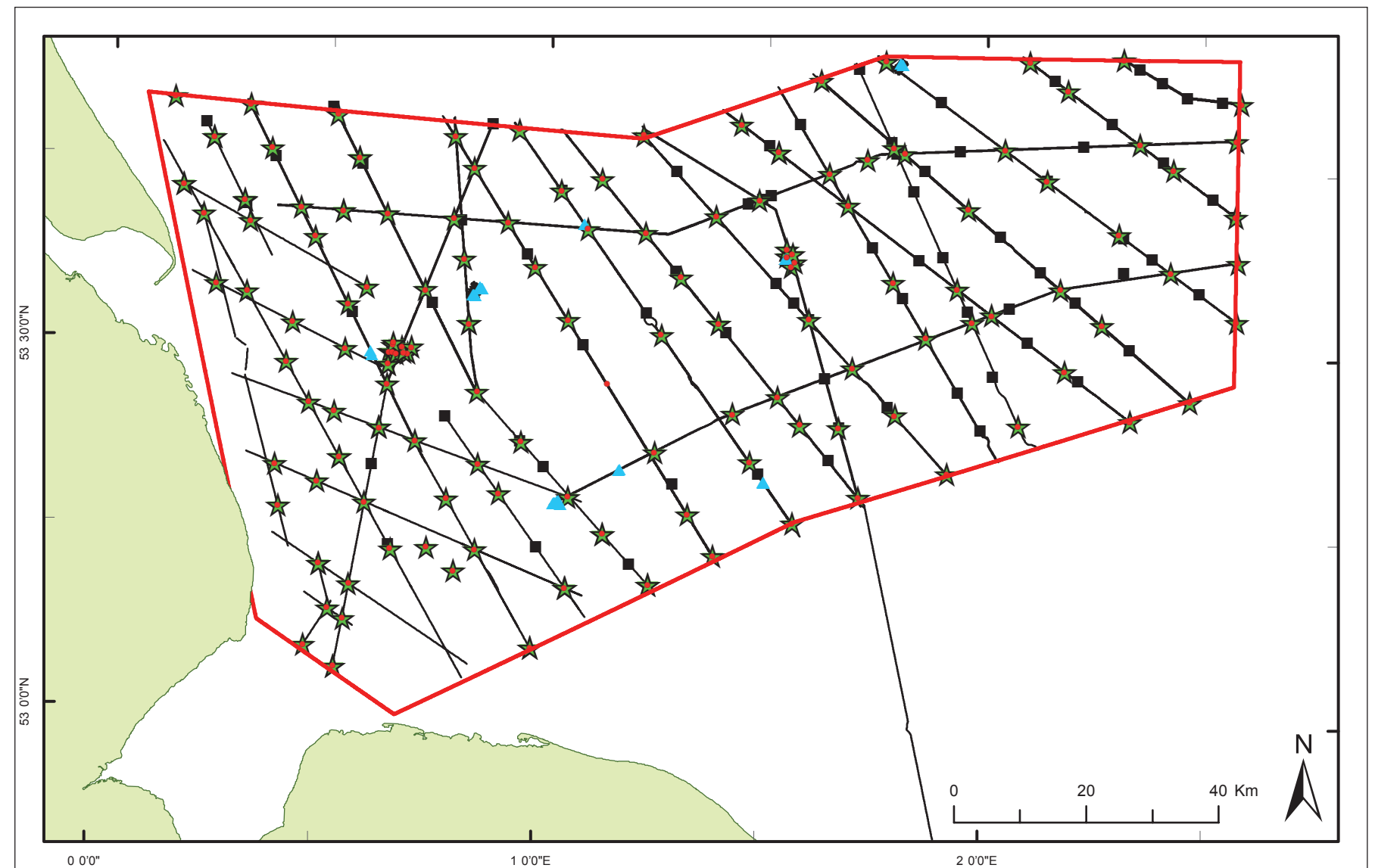
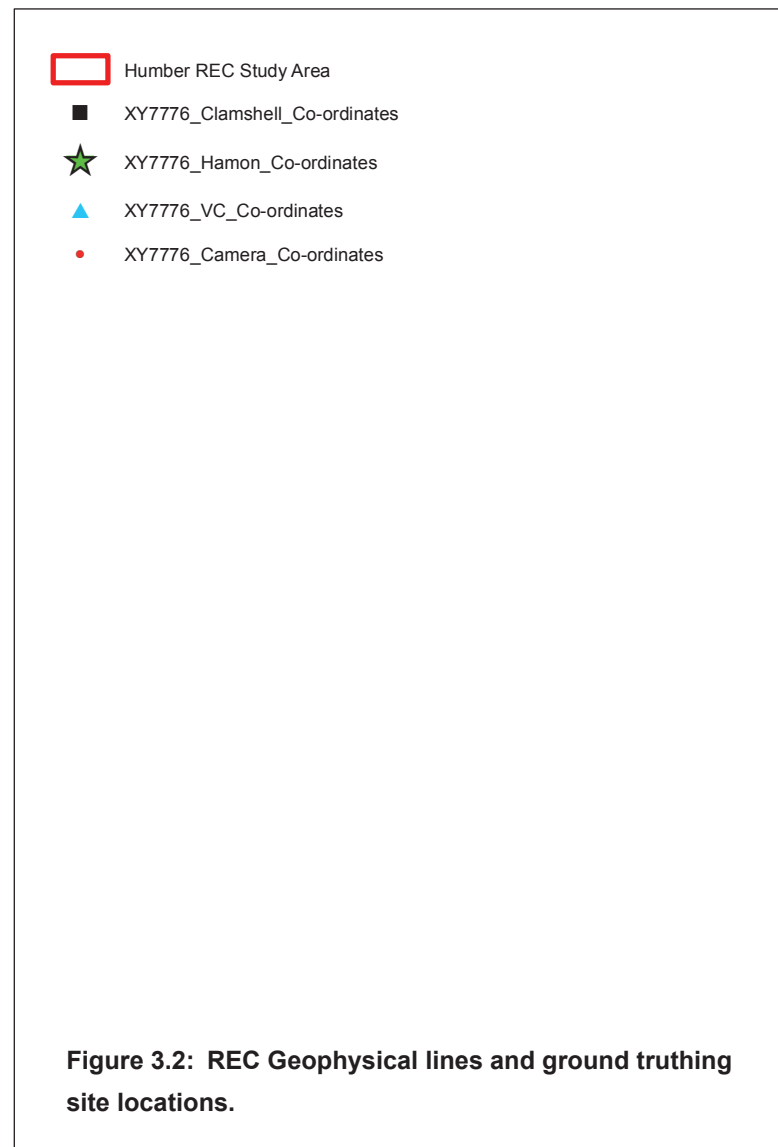
Clamshell Grab

Bulk sediment samples for PSD were acquired using a steel 300 litre Kinshofer Hydraulic Bucket Clamshell grab. Sample positions were recorded as GPS fixes taken when the grab reached the sea floor. On recovery, samples were inspected for suitability and rejected if the grab did not operate properly. Excessive surface water was removed and biologists observed and noted the *in situ* seabed on the sediment surface. As the grab opened a photograph of the sedimentary sequence sampled was taken. After emptying, seabed sediment samples were photographed on deck in a purpose-built hopper. The sample was then homogenised by mixing with a shovel, and a 10-litre subsample taken for PSD by Gardline Environmental.

74 of the 84 planned sites were occupied, with at least one particle size determination (PSD) sub-sample retained from all but one of these locations (site CL4). A total of 95 deployments were carried out across the 74 sites to achieve the samples obtained.

Vibrocorer (VC)

A Gardline Geosciences 5 m vibrocorer was used to collect continuous 86 mm diameter samples from 25 sites within the survey area. Clear core liners were used in all cases except where optically stimulated luminescence (OSL) dating was required when opaque liners were used. Sampling was attempted at 25 of the 49 proposed sites, with clear liner core samples retained from all 25. A total of 38 deployments were carried out to achieve the results obtained. Of the 25 sites sampled 9 required a 2nd attempt to acquire an acceptable sample. In addition, 4 sites were further sampled using opaque core liners for OSL analysis.



Sea Bed Imagery

A drop camera frame equipped with a Kongsberg OE14-208 underwater camera was used to obtain images of the sea bed at each of the sampling stations prior to deployment of any other instrumentation following methods described by James *et al.* (2010). At each sampling station the camera was towed along a transect (approx 100 m in length) passing as close to the target sampling point as practical under the prevailing weather and sea conditions. The camera was used to record both video and stills images, the latter being manually triggered at 1 minute intervals accompanied by a manual position fix.

Following a review of the video results an assessment was made of the suitability of the proposed sampling instrumentation. Thus in areas of coarse and irregular seabed the intended trawl sites were relocated.

Analysis of the seabed video and stills was undertaken by Gardline Environmental Ltd, using guidelines drafted by the National Marine Biological Analytical Quality Control (NMBAQC, 2009). The seabed composition and conspicuous fauna were recorded from 5 minutes of video footage taken at each station. Three representative images were then identified for each broad habitat identified and

these were then analysed in more detail, where possible classifying them according to the EUNIS biotope classification.

Hamon Grab

Benthic samples were collected for faunal and granulometric (particle size) analysis using a 0.1 m² Hamon grab. Single samples were collected from each of the 90 target stations as well as from a further 45 stations, giving a total of 135 Hamon grab samples.

The grab used on this survey is capable of collecting samples up to 12 litres in volume. Only grab samples with an estimated 50% capacity and no evidence of wash out were retained. In the event

that these criteria were not satisfied, repeat attempts were made to obtain viable samples and professional judgement used to assess sample acceptability. All retained samples were visually examined, described and then photographed so as to obtain a permanent record of the survey.

Samples intended for biological analysis were processed in line with standard protocols (Boyd *et al.* 2002; James *et al.* 2007; James *et al.* 2010). A representative sub-sample (250–500 ml) was retained for granulometric analysis before the remaining material was sieved through a 1 mm mesh and preserved in a 4% formal-saline solution for subsequent analysis.

Granulometric analysis was carried out by Setech (Gardline's geotechnical consultancy) using wet-sieving on the Wentworth scale (1 phi units). Data were expressed as the cumulative percent passing through each sieve, and were converted to absolute percentage retained on each sieve. Sediment statistics, including kurtosis and sorting were also calculated using this data.

Faunal analysis of the grab samples was undertaken by Marine Ecological Surveys Ltd., a participant in the NMBAQC scheme. All taxa present were identified to species level (where possible) and their abundance recorded. Taxa were then sorted into major faunal groups and blotted wet weight measured for Annelida, Crustacean Mollusca, Echinodermata and Miscellania (including porifera, bryozoa and other fauna). These weights were converted to grams ash-free dry weight (g AFDW) using conversion factors identified by Eleftheriou & Basford (1989). Data records were compiled in a UNICORN database and coded using the species codes of Howson & Picton (1997).

Scientific Beam Trawls

A 2 m scientific beam trawl with a 5 mm mesh liner was used to sample epibenthic fauna at 30 stations. The trawl was towed at a speed of 1.5 knots for approximately 10 minutes. The retrieved catches were photographed and analysed on deck in accordance with standard protocols (Boyd *et al.* 2002; James *et al.* 2007; James *et al.* 2010). The total sample volume, as well as the volume of sample made up by algae, shell and boulders was recorded. Commercially important fish and shellfish species were identified, counted, measured and weighed (grams wet weight) before being returned to the sea. The remaining sample was then washed over a 5 mm sieve, erect colonial organisms were removed from the

substrate as were any mobile epifauna all of which were identified, counted and weighed (grams wet weight).

Where the substrate was covered in encrusting colonial organisms, these were removed, identified and their percentage cover calculated. Where species identification was not possible on the survey vessel specimens were preserved in a 4% formal-saline solution and returned to Marine Ecological Surveys Ltd for microscopic identification.

3.3 Additional BGS Legacy Data

In addition to the geophysical data acquired during the REC surveys of 2008 and 2009, legacy data from the BGS archives were used in the interpretation, particularly Boomer data from surveys carried out in 1980 and 1990 (Figure 3.3). In addition to the geophysical data, 654 PSD's (Figure 3.4) from the BGS database were used, and in combination with the SeaZone bathymetry data, allowed the complete remapping of the sediment distribution in the REC area. Descriptions from an additional 363 shallow cores provided critical data in mapping the extent of pre-Quaternary bedrock at the seabed and the distribution of thin (cm thick) mobile sediment cover and the areas where the Bolders Bank Formation was at or close to seabed.

3.4 Geological and Archaeological timescales

Depending on the context, 3 different timescales are used within the report: British Stages(Geological), North West European Stages (Geological), and Archaeological. Figure 3.5 is provided as a reference for comparison.

3.5 Humber REC Geographical Information System (GIS) and Database

All data collected and results produced for the Humber REC study have been placed in a Geographical Information System (GIS). A GIS facilitates the integration of disparate sources of geographical and non-geographical information into a single environment for visualisation, querying and analysis.

ESRI ArcGIS 9.3 software was used as the GIS system for the study. All data identified during the data review at the beginning of the study was collated as metadata in the GIS system.

In parallel with the GIS, all biological, physical, archaeological and geological data, analysis and results from the study are stored using a Microsoft Access 2003 database. All position data was given a unique identifier based on a station number, which can be linked to the results of the biological and geological data and results. This allows users to extract required data easily by developing custom database queries

The development of the database and GIS has also allowed direct linkage between the Access database and the GIS. By joining the geographical positions in the GIS to the relevant biological and geological data from the database, it is possible to instantly access the data stored in the database from the GIS. This facilitates the production of maps from data stored in the database or simple data querying.

3.5.1 Contents of the Humber REC DVD-ROM

When the DVD-ROM is opened, a number of folders and files are displayed. Table 3.1 outlines the contents of each folder. The Humber REC GIS can be used directly from the DVD-ROM or by copying the entire contents of the DVD-ROM to a single user PC, using the same folder structure as on the DVD-ROM.

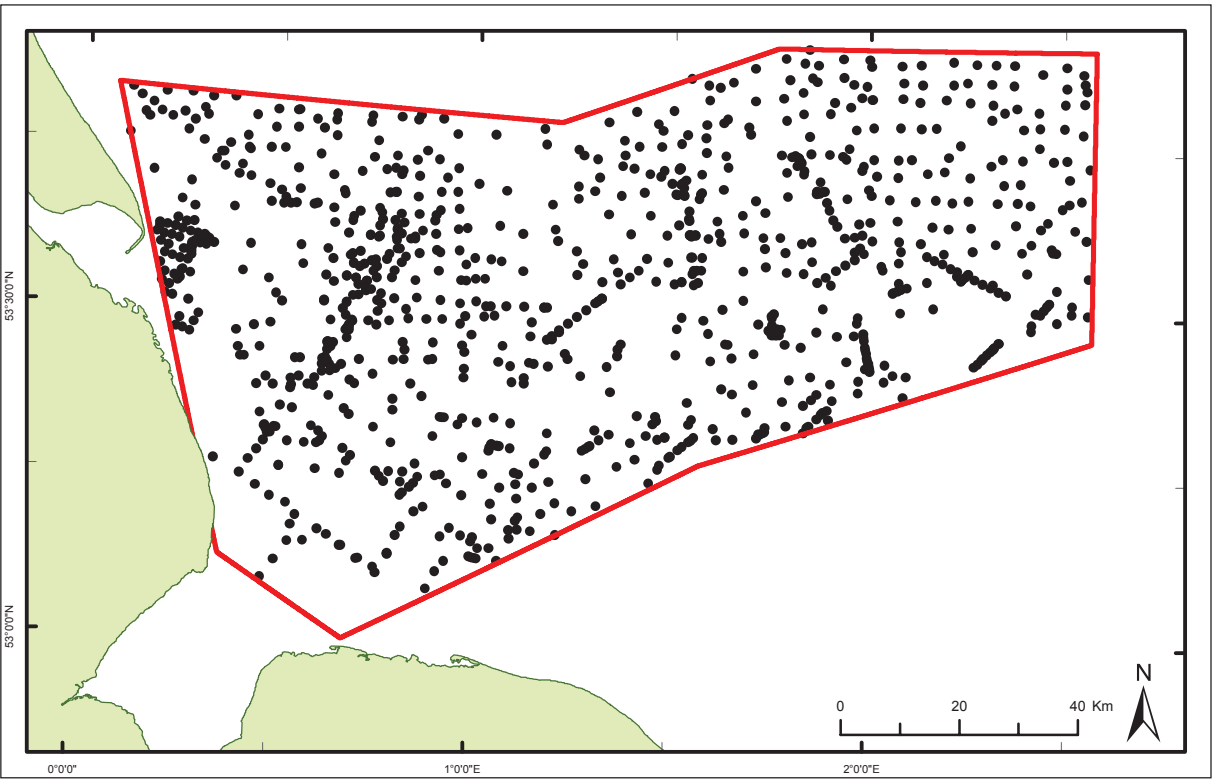
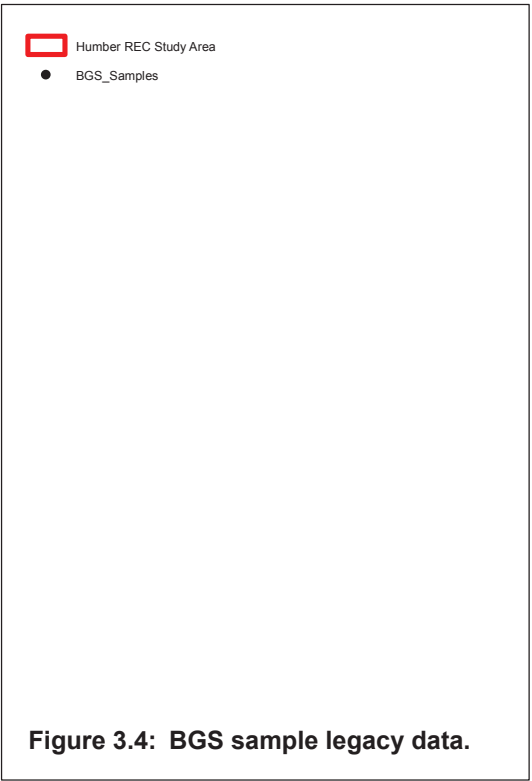
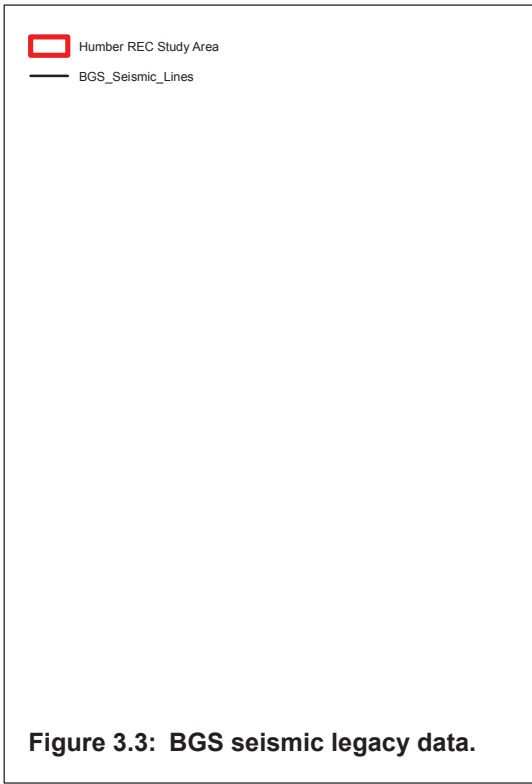
Metadata

Metadata information has been completed in accordance with the ISO 19115 metadata standard for all GIS layers provided on the DVD-ROM that accompanies this report. The mandatory information to meet this standard are:

- Creation data and language,
- Themes and categories,
- Abstract,
- Metadata author.

Co-ordinate System

All data and maps produced as part of this project are projected to the Universal Transverse Mercator (UTM) Zone 31 North coordinate system with reference to the WGS84 datum. Some of the historical data included in the GIS are re-projected to UTM 31 from different coordinate systems.



Top_Level_Folder	Subfolder or File	Subfolder or File	Description
Humber_REC_Digital_Deliverables		HUMBER_REC_COMPLETE.pdf, HUMBER_REC_COMPLETE_lowres.pdf	Report pdfs — high and low resolution versions:
		MEPF_Metadata_Proforma.xlsx	ArcGIS metadata proforma
	Appendices		Appendices A-E
	Humber_REC_GIS_DATA	ArcReader	This folder holds the GIS file that should be opened if ArcReader is being used.
		SHAPEFILES	This folder has copies of the spatial data stored as ESRI shapefiles for use within any ESRI GIS or in ESRI ArcGIS in conjunction with the layer files.
		LAYER_FILES	This folder contains ESRI .lyr files which store the symbology for each of the layers within the GIS. These can be used with the shapefiles to add the data into your own ESRI ArcGIS.
		Humber_REC_GIS.mxd	If you already have ArcGIS installed on your machine you can open this file directly to view the project GIS. Two versions for ArcGIS 9.3 and 9.2.
		Humber_REC_GIS.mdb	Personal geodatabase containing the GIS data. It is possible to view the spatial extent of this data within the GIS or to independently view the associated tables within Microsoft Access.

Table 3.1: GIS content of the Humber REC DVD-ROM.

3.5.2 Using the Humber REC GIS

ESRI ArcGIS Users

The Humber REC GIS uses ESRI ArcGIS 9.3 software and stores all spatial data and associated metadata within a personal geodatabase. The GIS is available on the accompanying DVD-ROM and can be viewed with a licence for ESRI ArcGIS software. To view, copy the data on the DVD-ROM to a local drive and then open Humber_REC_Dissemination_GIS_93.mxd map document file.

Free GIS Viewer

For those users who do not have access to an ESRI ArcGIS licence the Humber REC GIS can also be read using ArcReader which is a free downloadable GIS viewer. ArcReader can be installed using the executable within the folder on the

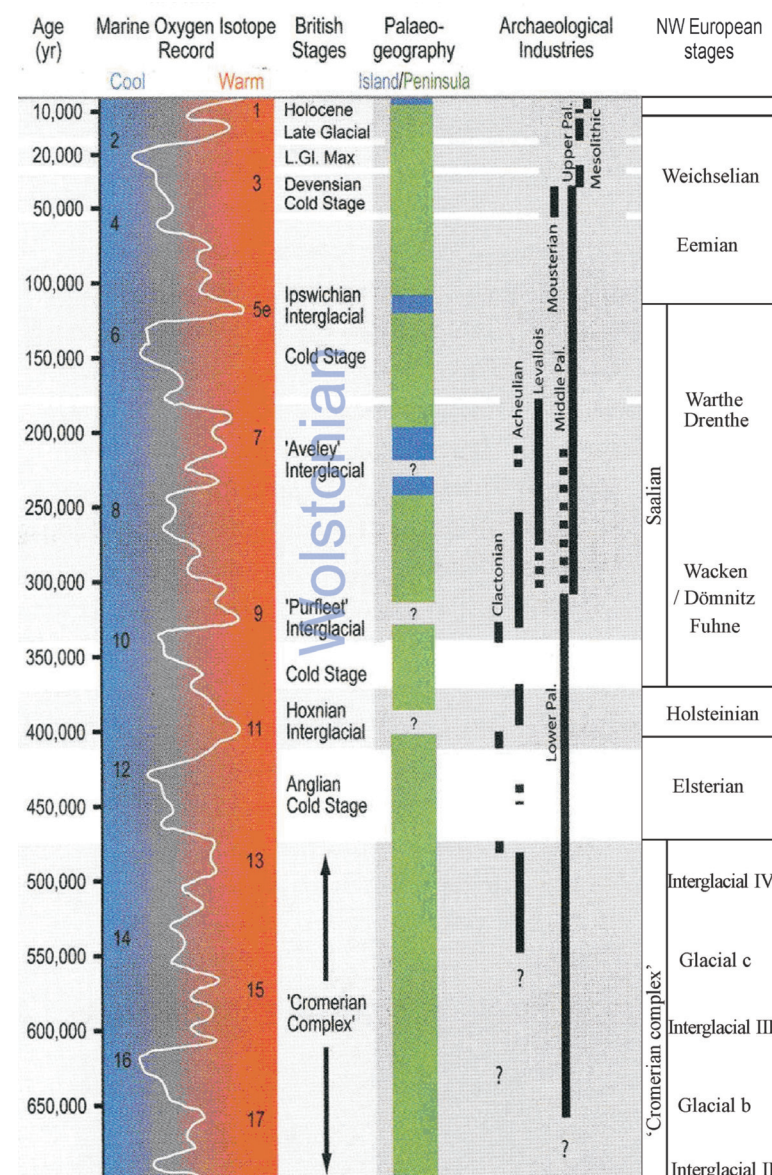


Figure 3.5: Palaeogeography, and oxygen isotope record with reference to relative geological and archaeological stages. Redrawn after Stringer, 2006 and Gibbard *et al.* 2007.

accompanying DVD-ROM or by visiting the ESRI website (<http://www.esri.com/software/arcgis/arcreader/download.html>). Once ArcReader software has been installed on a machine, the user can open the Humber_REC_Dissemination_GIS_93.pmf file and view the data stored within the GIS.

3.5.3 Data Availability and Usage

Original data acquired by the Humber REC study is freely available. Any copyrighted data licenced to the Humber REC study is not freely available through the GIS. Its use is subject to the terms and conditions of the copyright holders.

A web based GIS of the results of the Humber REC study will be available through the Marine ALSF website (<http://www.marinealsf.org.uk/>).

4 Geological Characterisation

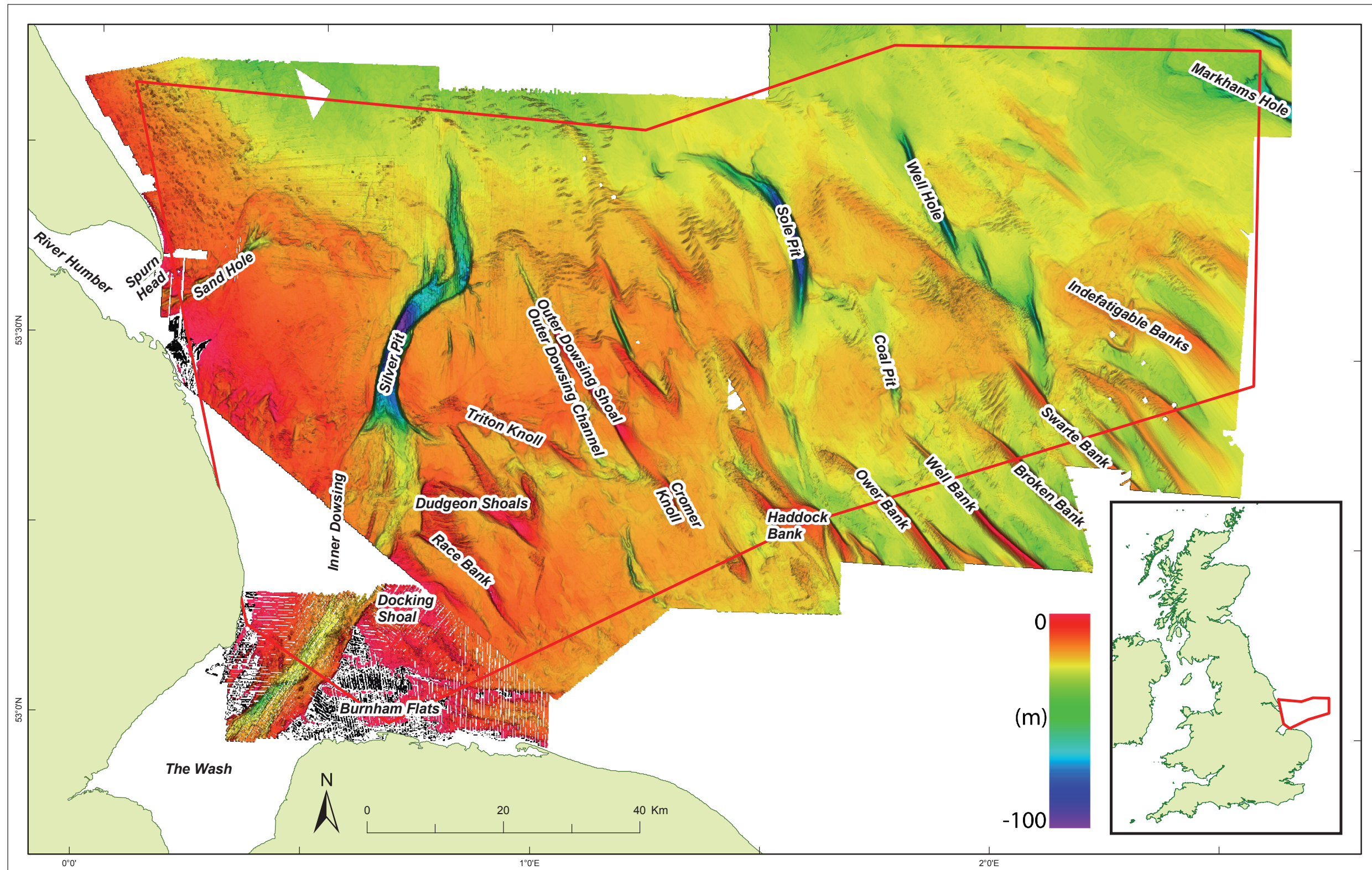


Figure 4.2.1: Bathymetry (SeaZone) of the Humber REC area (100 m resolution). SeaZone bathymetry is gridded single beam echo sounder data. Single beam echo sounder data © British Crown & SeaZone Solutions Ltd. Licence No. 052008.012. All rights reserved.

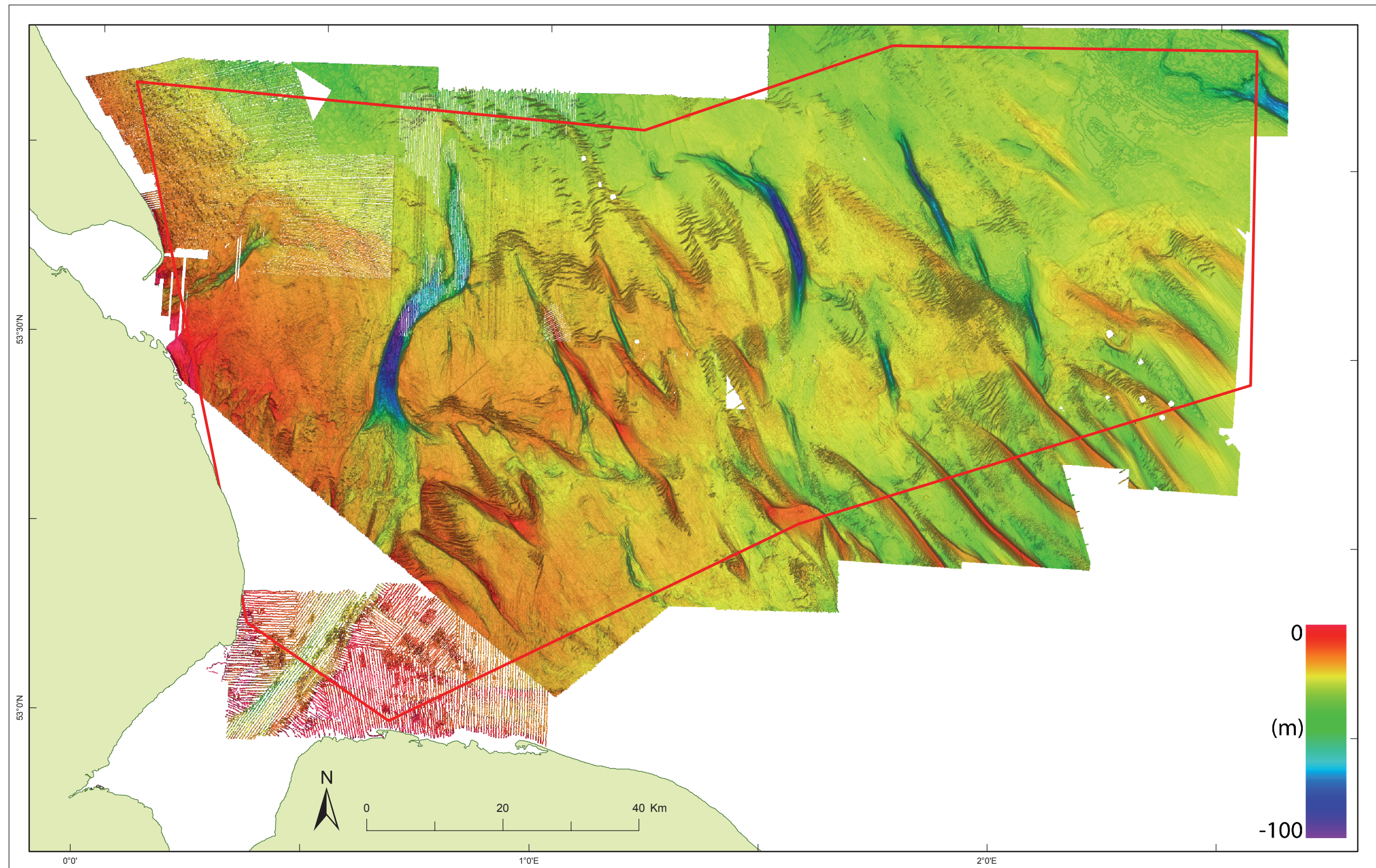


Figure 4.2.2: Comparison SeaZone bathymetry gridded at 60 m resolution. SeaZone bathymetry is gridded single beam echo sounder data. Single beam echo sounder data
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4.1 Introduction

Geological Characterisation for the broadscale mapping of the Humber REC requires a knowledge of the sea bed morphology and the immediately (less than a metre) underlying sediment and rock. It not only describes the non-living environment but also provides a context for mapping other aspects of the sea bed, such as the living habitat and characterising biotopes. In terms of the archaeology, geological characterisation of the sea bed applies to mapping palaeolandscapes that may lead to the identification of sites of Mesolithic human habitation. It is the physical sea bed environment therefore, together with the underlying few metres of rock and sediment that is fundamental to understanding the overall natural environment of the Humber REC area.

4.2 Interpretation Methodology

To characterise the Humber REC region it was originally planned to follow the methodology developed by James *et al.* (2007) in the Eastern English Channel Marine Habitat Map (EECMHM) and modified for the South Coast REC (James *et al.* 2010). However, the geology of the Humber area is very different to that of the English Channel. For example, in the Humber there are no large areas of bedrock at (or close to) sea bed. There are, however, large areas of relict sediments that are inactive under the present hydrodynamic regime, but provide habitats for the living biota. There are numerous river channels but, unlike those in the South Coast REC area, they are small and, with the regionally limited data set, difficult to map individually. Thus, it was necessary to modify the methodology applied to the English Channel REC areas although the interpretation is still primarily based on geophysical data, integrated with, and ground-truthed by, samples of sediment and rock from the sea bed.

In formulating the mapping methodology, the main considerations were the size of the Humber REC area (11 000 km²), which is large in comparison to other RECs (for example the East Coast area is ~3 000 km²), as well as the volume and scale of the data (geophysical and sampling) available. Broadscale mapping was required to fulfill the main objectives of the project. For example, utilizing regional data sets like the SeaZone bathymetry (Figures 4.2.1 and 4.2.2) provides excellent large-scale sea bed morphology. Interpreting this data in conjunction with the REC survey data resulted in the regional bedform map. Integrating

the SeaZone data and REC multibeam echo sounder (MBES) data with the PSD statistics from sediment samples provided the distribution map of the sea bed sediment and the identification and mapping of the large-scale bedforms. The BGS legacy data provided added confidence to the interpretation of the sea bed sediment distribution. It was used to extrapolate the interpretation of sea bed morphology and sediment distribution between the REC geophysical corridors and lines. The REC geophysical survey data provided the high resolution data set for interpretation of the smaller-scale sea bed detail. However, it is geographically limited and, in comparison with the large size of the REC area, the Corridors and lines are relatively narrow (100s metres) and, at 10 km, widely separated (Figure 3.1).

Representative figures are included as hard copy in the report, but all of the interpretations are available on the GIS. The GIS is particularly important in viewing the small-scale sea bed features, such as sand ribbons, small sand waves and gravel patches, not easily illustrated on regional-scale hard copy figures. Although the data is presented in ARC GIS, interpretation of the bathymetry as sea bed morphology was undertaken using Fledermaus IVS 3D visualisation software.

The result of the geological characterisation is a series of sea bed maps that, not only show the main sea bed morphology and sediment distribution, but also, if somewhat subjectively, the level of confidence that can be placed on the interpretations. The figures representing the results of the mapping are presented in Figures 4.2.1 to 4.2.13.

4.2.1 Broadscale Sea Bed Feature and Sediment Mapping

Our approach therefore was to first map the broadscale elements of the area. The main morphological features were interpreted from the SeaZone data. The xyz data were gridded in Fledermaus and ARC GIS. Because SeaZone source data varied in geographical density, we gridded at a resolution of 100 m to avoid spatial aliasing (Figure 4.2.1 and 4.2.2) and at 60 m (Figure 4.2.1 and 4.2.2) to capture smaller scale features where the data was of sufficient density (Figure 4.2.2). The SeaZone data were integrated with the BGS legacy maps and samples, together with the new REC sample and geophysical data (MBES and Backscatter) to remap the sea bed sediment distribution using the Folk classification scheme. The existing BGS Sea Bed Sediment

maps were honoured except where the regional morphology from SeaZone, geophysical or sampling data dictated otherwise. The result was a revised Folk sea bed sediment distribution map (Figures 4.2.3 and 4.2.4; compare with Figure 2.3.5) and a new large-sale bedform map (Figure 4.2.5). The sedimentary terminology and descriptions of the bedforms are based on the publications of Allen (1969), Pantin, (1991), Collinson *et al.* (1982), Reineck and Singh (1980), Stanley and Swift (1976), Stride *et al.* (1982) and the in press classification of offshore East Anglia (Personal Communication; Carol Cotterill, BGS).

Large-scale features mapped are:

- **Sand banks:** dimensions - Length = ≤80 km, width (average) = 13 km, Height = 10's ms. Where active or semi-active (maintained), Stoss slope ~1°, Avalanche slope ~6° (moribund banks will have smaller slopes). They are asymmetrical and migrate in the direction of the steepest (avalanche) face. They are active where currents >0.5 m/s. Major axis is at oblique angle (7–15° counterclockwise to current flow). Varying morphologies are dependent on hydrodynamic/geographic situation. In the Humber REC area there are open-shelf linear banks and more complex sinuous banks,
- **Sand waves:** dimensions – wavelength = 30 m to kms, height = 1.5 m-10's m's. Their major axis is typically normal or oblique to current direction; sediment movement is in the direction of their steepest slope. In plan view they are typically sinuous. Morphologies are diverse and again depend on local hydrodynamic conditions, and sediment supply and character. They may be: Symmetric (where the peak tidal current amplitude is bimodal), Asymmetric (where the tidal current is predominantly unidirectional), Barchan (isolated, lunate shaped), Parasitic (located on larger sand banks), Catback (humped profile indicates bimodal tidal currents), and Bifurcated (branched),
- **Sediment Waves:** This is a generic classification given to the sediment waves in the west of the REC area, where there is insufficient data to determine whether the features are 'sand waves' or have a significant gravel component. Same morphological descriptions as sand waves apply, however if they are gravel waves, higher amplitude currents are required to form and maintain them.

Humber REC Study Area

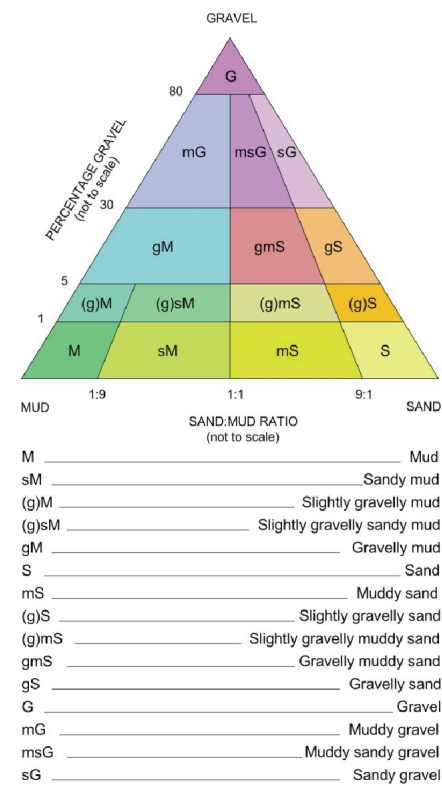
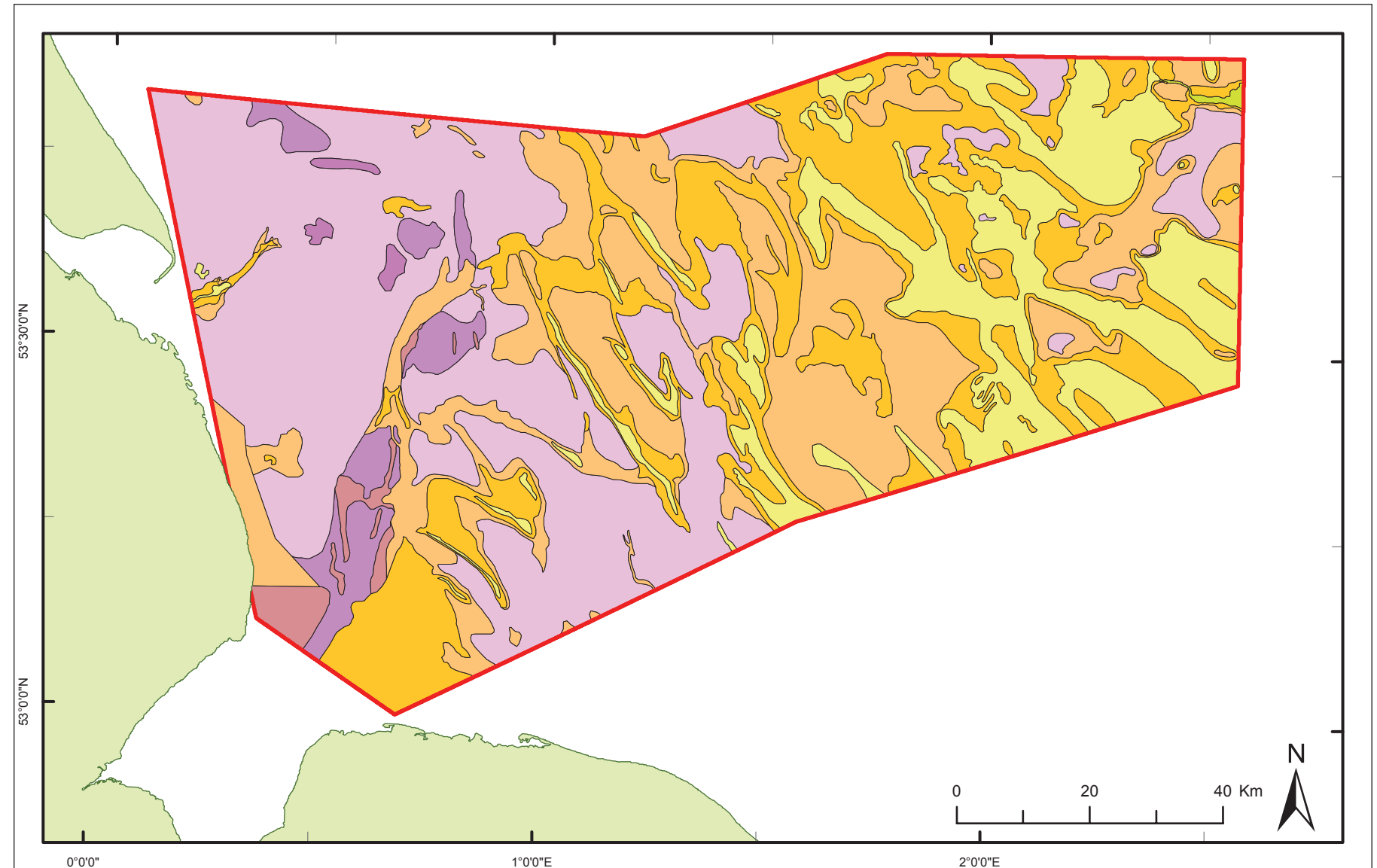


Figure 4.2.3: Seabed sediment distribution map based on the Folk classification (Folk, R L, 1954).



- **Tunnel Valleys or Deeps:** large-scale valley with flat floor and steep sides, often with an irregular longitudinal profile. Typically >100 m wide and >1 km long. Often scaphiform (scooped) in shape. Interpreted as formed sub-glacially at the ice-margin, or, alternatively by catastrophic water outbursts.
- **Glacio-fluvial outwash fan/plain (Sandur):** Broad, irregular, channelled sea bed with thin sediment cover (originally of poorly sorted sand and gravel) deposited in front of an ice sheet margin. The sediment distribution within this feature was extensively modified by marine transgression and is now primarily dominated by tidal currents in and out of the Wash, however the basic seabed morphology remains, and

- **Bedrock at surface:** thin (less than metre thickness) or absent sediment.

4.2.2 Small-scale Sea Bed Feature Mapping

The new REC multibeam echo sounder and derived backscatter together with sidescan sonar were then interpreted to map smaller-scale bedforms, such as sand patches and ribbons, grooves, smaller sand waves, and sediment distribution along the survey corridors and lines. Areas of sand and gravel were identified from MBES backscatter and sidescan sonar. The interpretations were validated by viewing sea bed imagery; stills photography and video. In addition, the video and still pictures were also used to identify where

possible the presence of bedrock or till (Bolders Bank Formation) at or near the sea bed. To effectively display on a regional map in hard copy the small scale sea bed features mapped (as we do with the banks and sand waves for example) is impossible; their distribution is best seen in the ARC GIS. Thus here we illustrate representative examples of individual features in Figures 4.2.31 to 4.2.44.

The small-scale features mapped are;

- **Areas of boulders:** concentrations of boulders, with boulder defined as larger than 256 mm (10") in diameter,
- **Areas of small sand waves (megaripples or dunes):** (height = 5 cm ~3 m, wavelength = 0.6–30 m). Wavelength increases

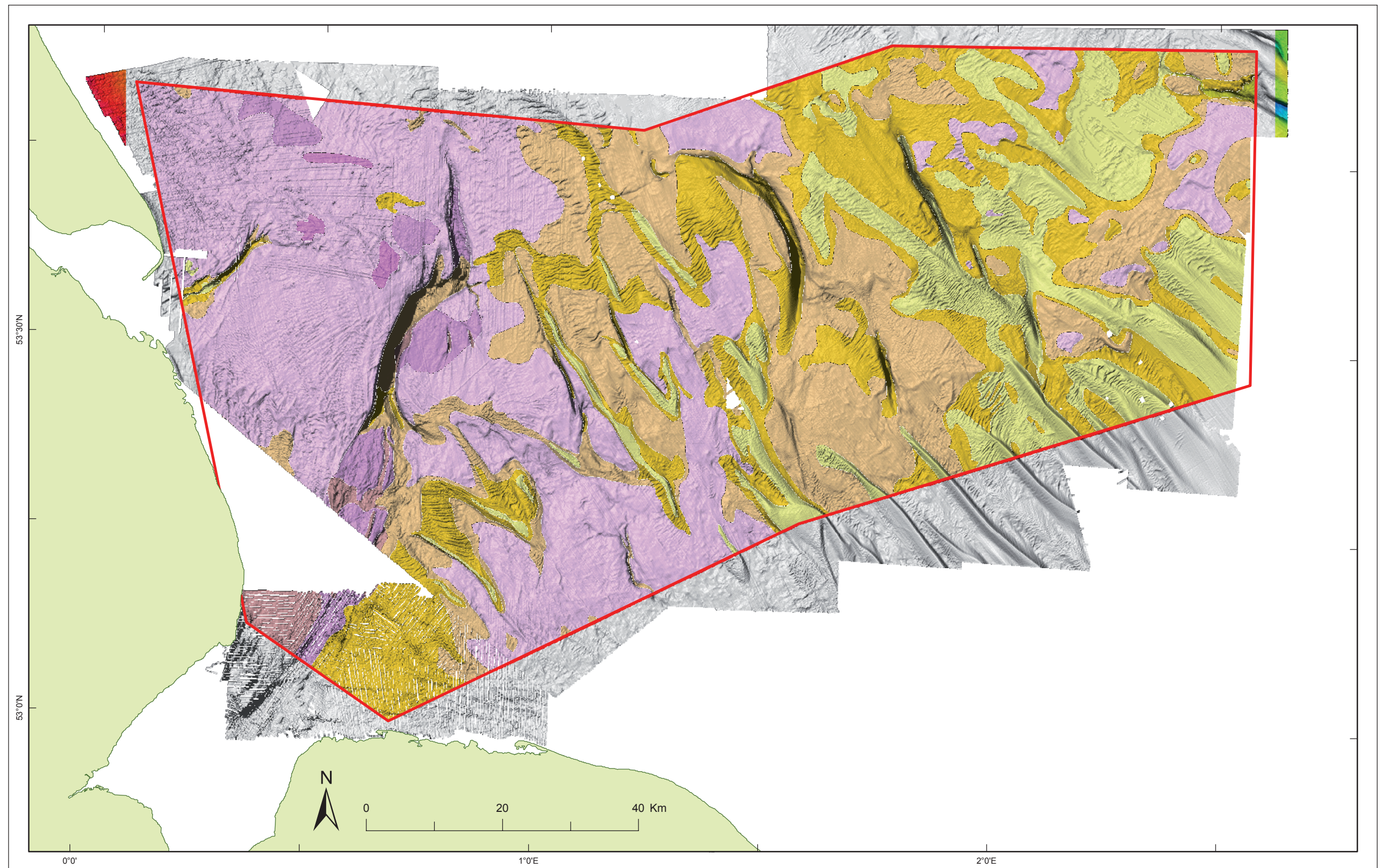
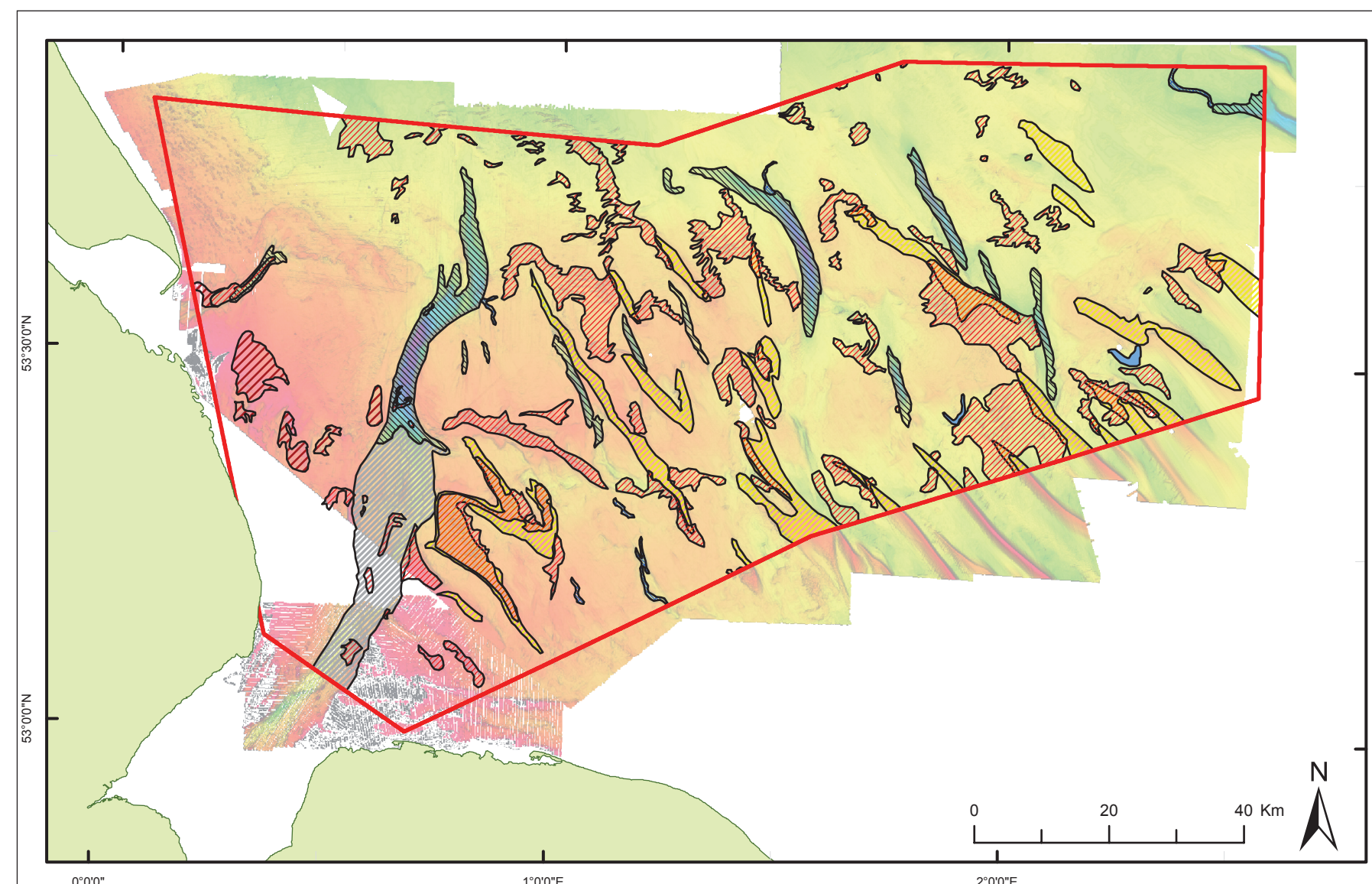
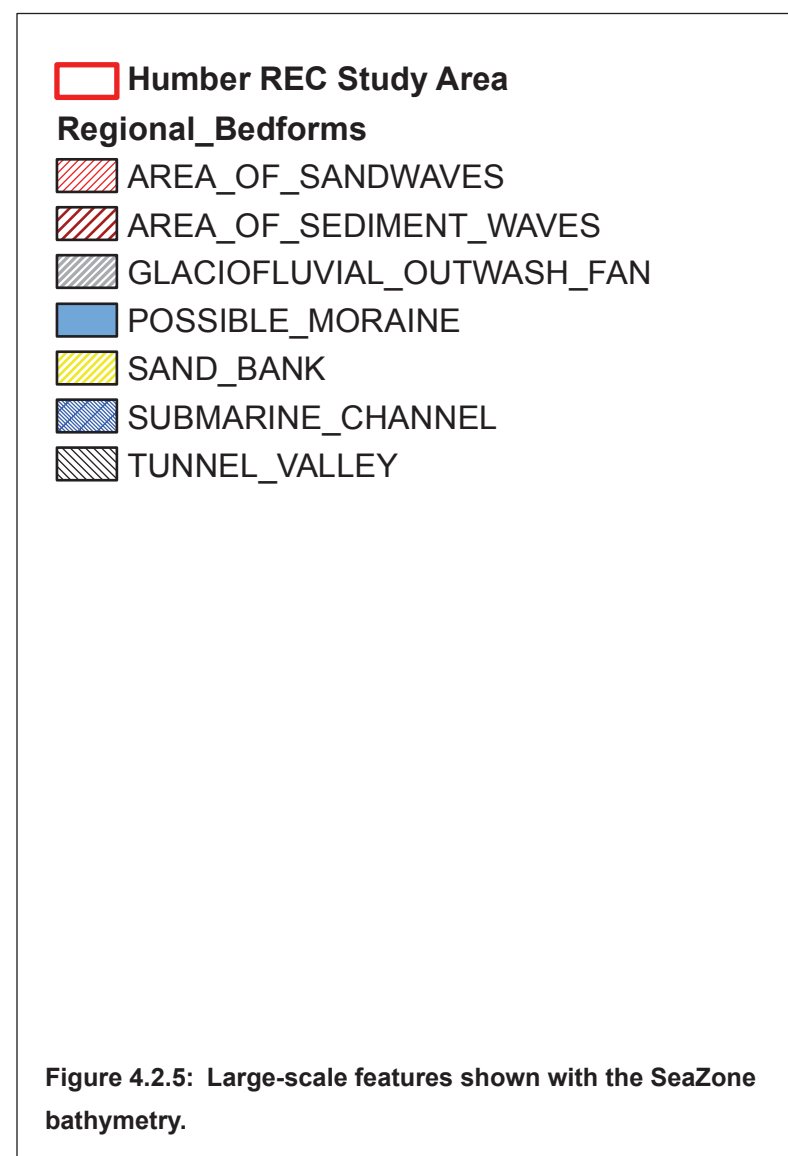


Figure 4.2.4: Folk Seabed sediment distribution map draped over the SeaZone bathymetry. (Single beam echo sounder data © British Crown & SeaZone Solutions Ltd. Licence No. 052008.012. All rights reserved).



with water depth. Sand waves rarely occur alone, and typically form 'fields'. Their crests tend to be sinuous. They form in conditions similar to those of the larger sand waves, but are distinct from (smaller-scale) ripples. They form where there is increased boundary shear stress and stream power (compared to ripples); the increase in bed shear stress results in a higher stream velocity, greater turbulence and a larger sediment bed load; leading to an abrupt change from ripples to smaller sand waves.

- **Sand wave crests:** Sand wave crests are mapped revealing the orientation of the observed sand waves.

- **Sand Ribbons:** elongate, low relief mobile sand bedforms that typically have a length:width ratio of at least 40:1. They are longitudinal, and are oriented parallel to the primary (net) bottom current direction.
- **Sand patches:** areas of thin sand cover that vary in thickness, but generally consist of a thin sand layer 'patches' resting on a gravelly substrate. The patches take a variety of forms ranging between continuous sheets and lingoidal islands.
- **Fluted and grooved sea bed:** elongate ridges and intervening grooves of low amplitude cut into rock, boulder clay or sediment. They are mainly identified from the MBES,

although they may be seen on the backscatter and SSS. Their specific origin is indeterminate, but is probably glacial but may be from strong current activity. It is a blanket term to classify most sea bed lineations that are of diverse morphology, and incised into or deposited on various sediment types. Grooves may be infilled with finer sediment than present on surrounding sea bed, or cut into fine sediment, exposing coarser sediments. Thus on backscatter data, bathymetric lows may appear bright (finer) or dark (coarser) relative to the bathymetric highs (Flutes). The predominant orientation of these features is NNW–SSE.

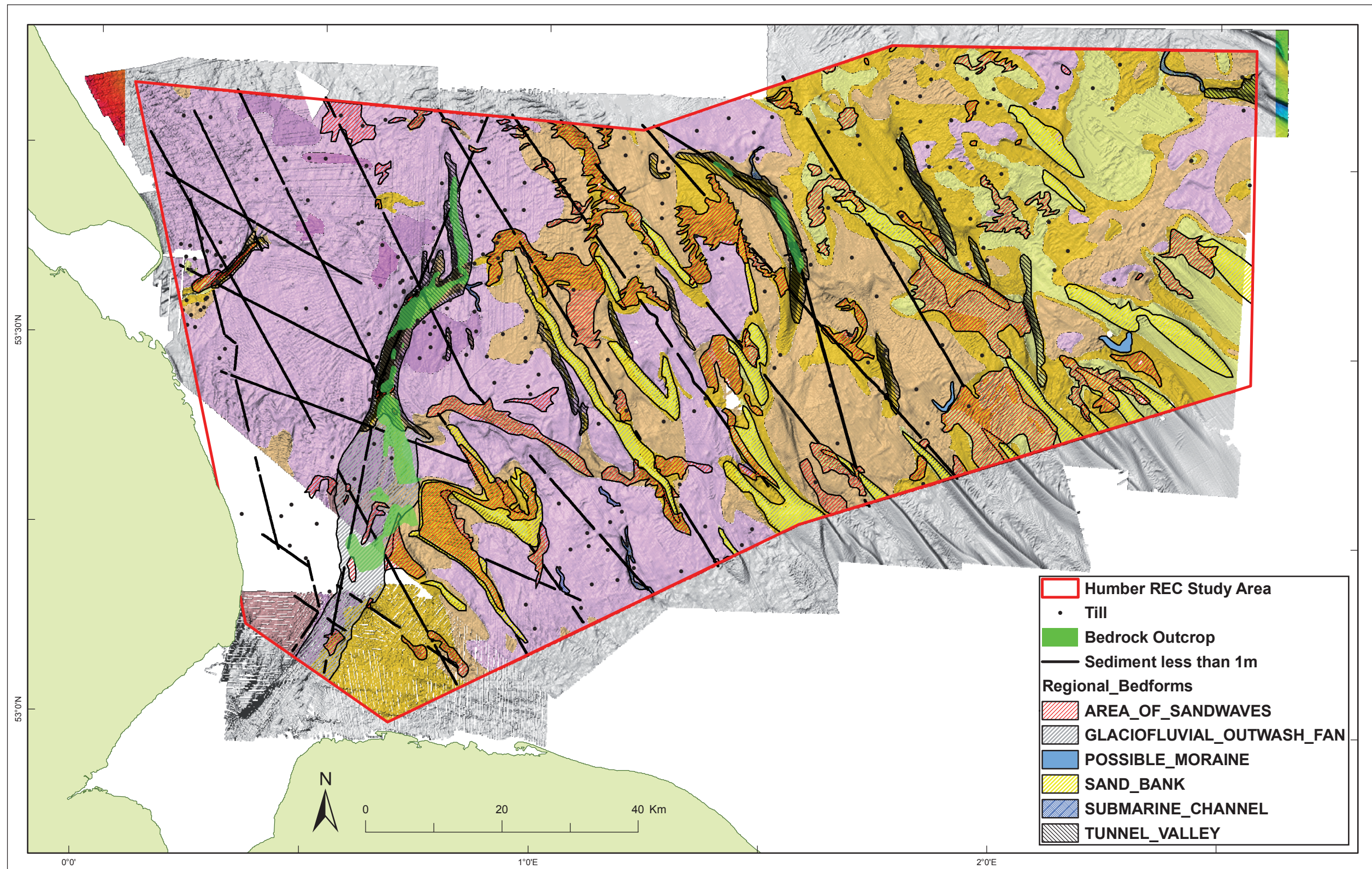


Figure 4.2.6: A composite map showing the Folk sediment distribution draped over the SeaZone bathymetry, large-scale features sediment less than 1.0 m interpreted from boomer data, seabed exposure of bedrock mapped from boomer data, and BGS legacy data of cores comprising till at or near the sea bed.

- **High relief and hummocky sea bed:** areas of rugged sea bed morphology: areas of hummocks interpreted as glacial in origin — eroded boulder clay for example, and
- **Rock at sea bed:** areas of absent or thin (less than one metre) sediment cover where bedrock is at or near sea bed.

4.2.3 Integration of Data-Sets

After mapping the sea bed from the MBES, backscatter and SSS the REC boomer data was interpreted to map the sub-sea bed architecture of the sedimentary and rock sequences present. These sequences are mainly of Quaternary age in the Humber REC area. Where mobile sediment was of sufficient thickness the internal structure of the sediment bodies was also interpreted. The boomer data was augmented by legacy BGS seismic data to improve

regional coverage. As noted by James *et al.* (2007) when sediment is less than 1 to 1.5 m thick the boomer data cannot be used to distinguish the rock/sediment interface. Therefore, areas where the boomer records did not resolve the sediment/rock interface are mapped as rock and thin sediment. BGS short core data was used to validate areas of thin sediment cover interpreted from the geophysics, as well as the lithology of the underlying bedrock or till.

As a result, areas of bedrock at the sea bed were mapped, together with the presence and extent of the Bolders Bank Formation. The Bolders Bank Formation is mainly till, but much of its surface is dissected by channels of the Botney Cut Formation. Botney Cut sediments may be fine silts and clays, that are identified by their seismic signature and, where available, core samples. Botney Cut sediments, however, may also comprise

gravel that is difficult to identify on seismic except by the (often vague) channel architecture in which the gravel accumulated. Where sediment thickness was mapped this is only of mobile sediment, that is not necessarily the total sediment present; some sediment is relict as noted previously. In a biological context, Boulder Clay or till is regarded as bedrock as it provides a similar, hard, habitat for the biota. Other features identified and mapped out as appropriate include, Botney Cut Channels, thick areas of sediment, and sand waves.

Integration of sea bed and subsea bed geophysical data and sediment and core samples results in Figure 4.2.6, a composite map produced from Folk sediment distribution draped on SeaZone bathymetry, large-scale bedforms mapped from SeaZone bathymetry, sediment less than 1.0 m interpreted from

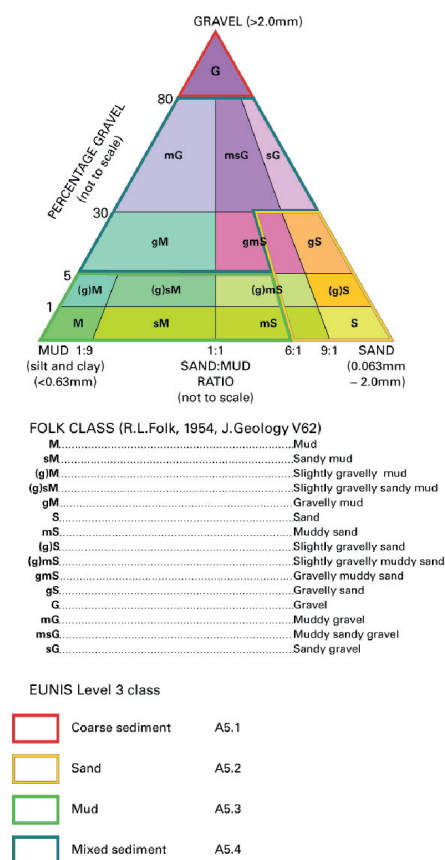
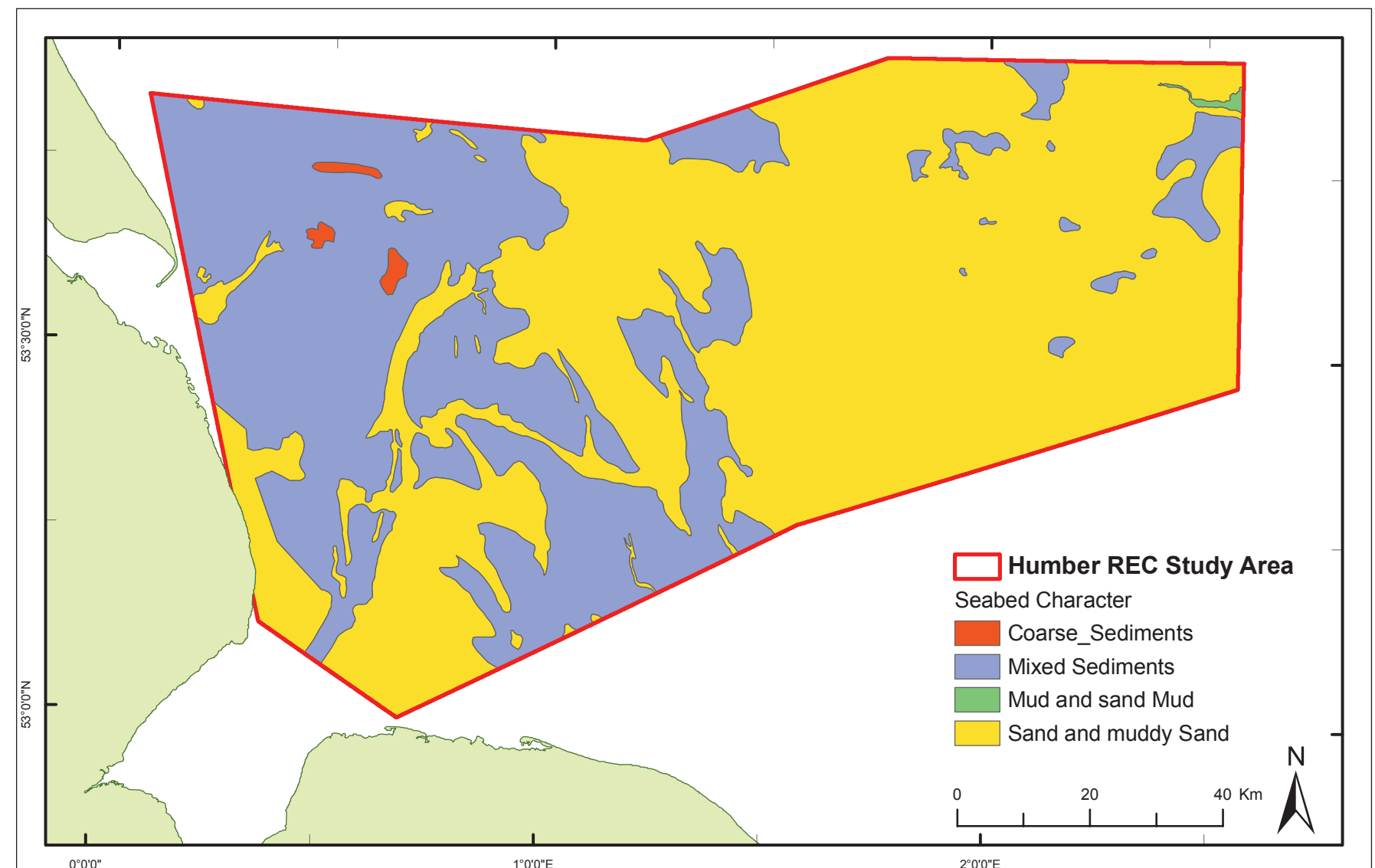


Figure 4.2.7: Seabed character map based on EUNIS level 3. Revised mapping methodology taken from James *et al.* (2010).



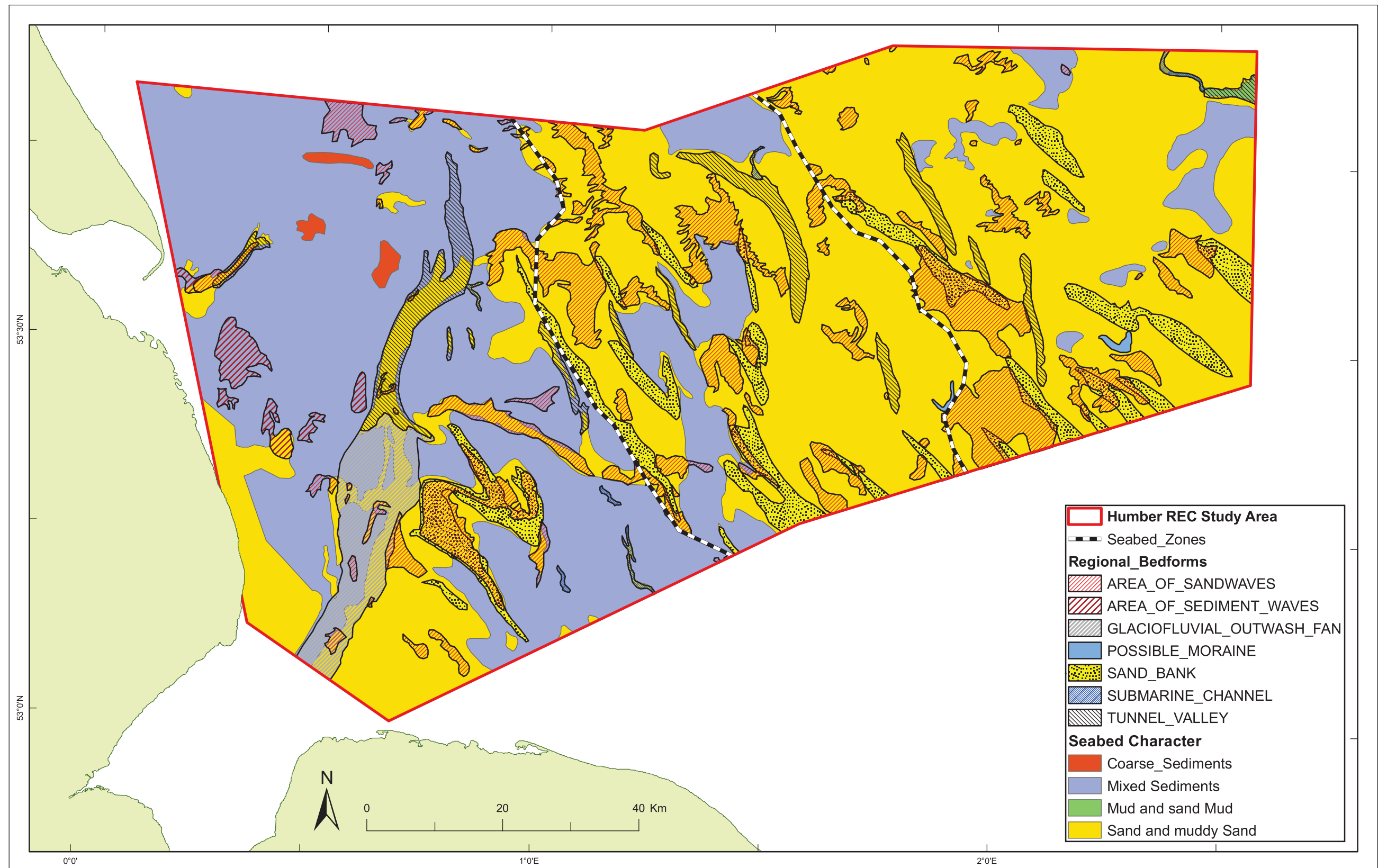


Figure 4.2.8: Seabed character map with overlay of large-scale features.

Boomer data, sea bed exposure of bedrock mapped from Boomer data and BGS legacy data of cores sampling till at or near the sea bed.

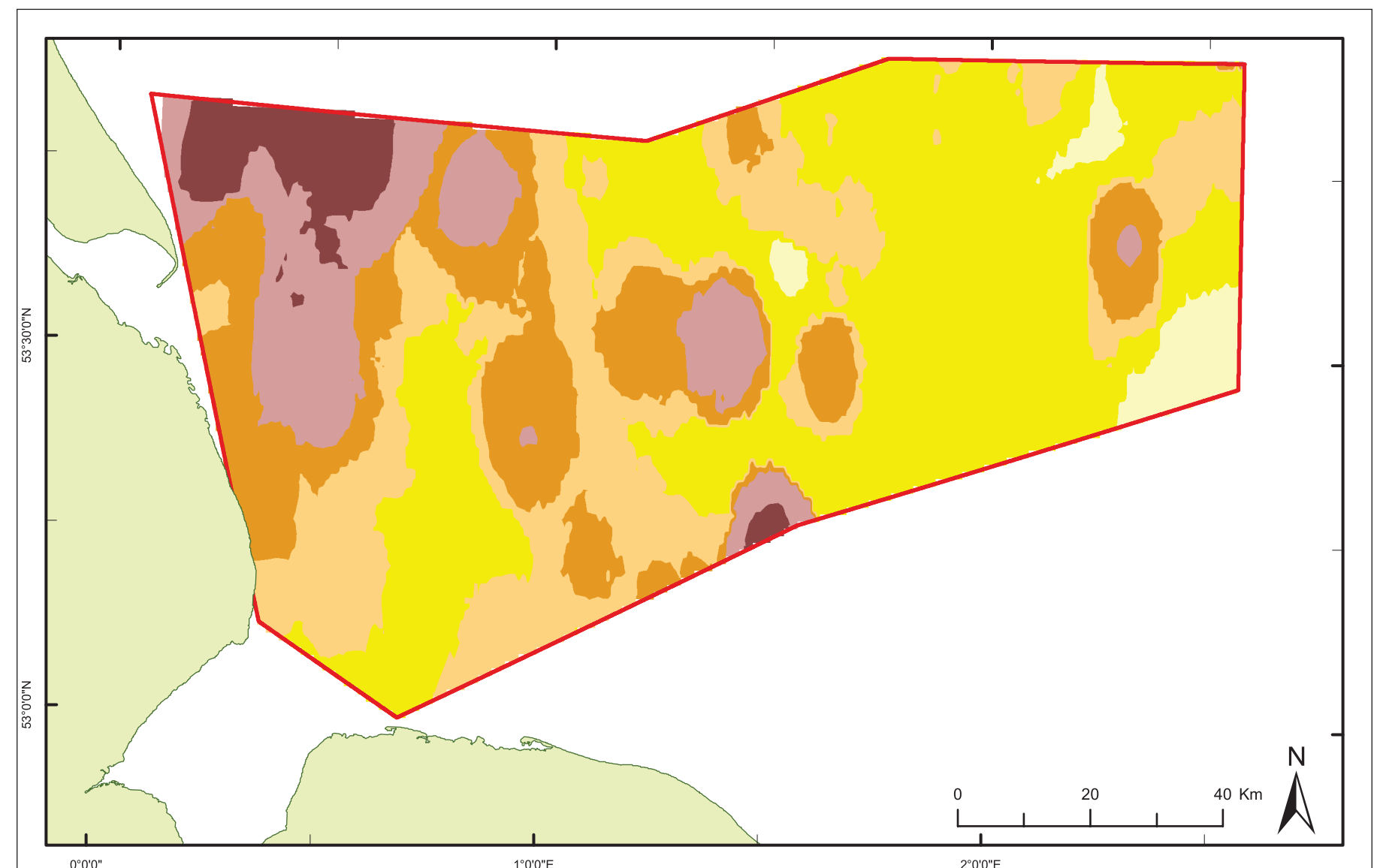
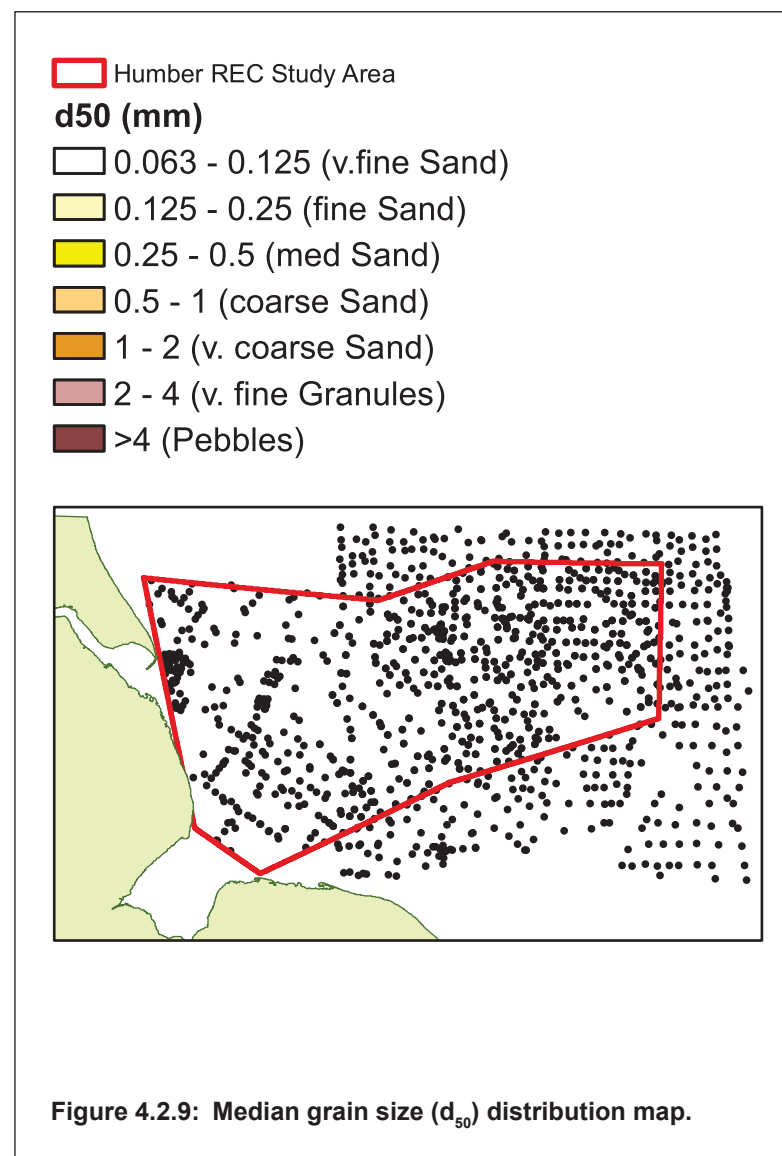
4.2.4 Sea bed Character Map

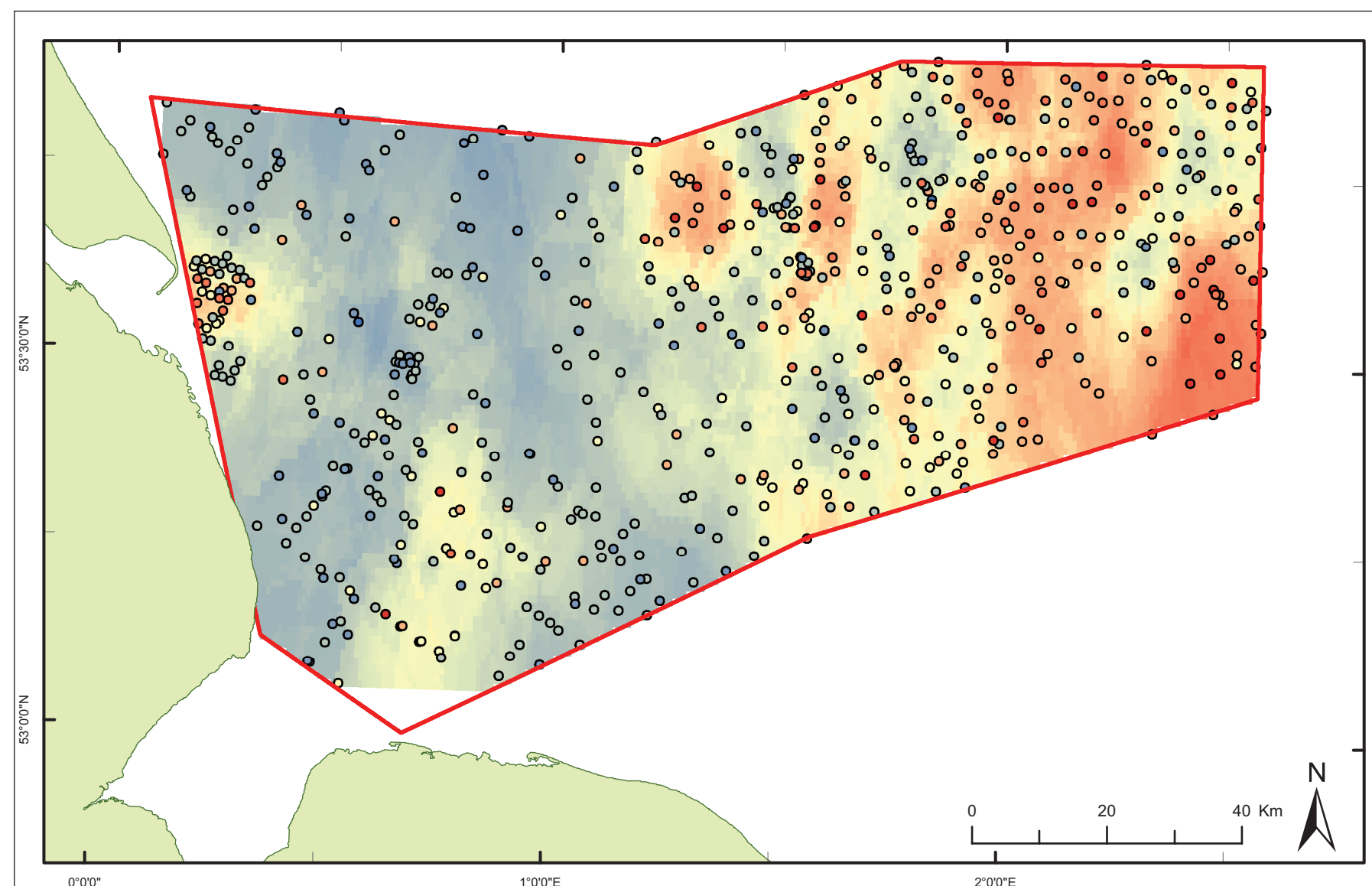
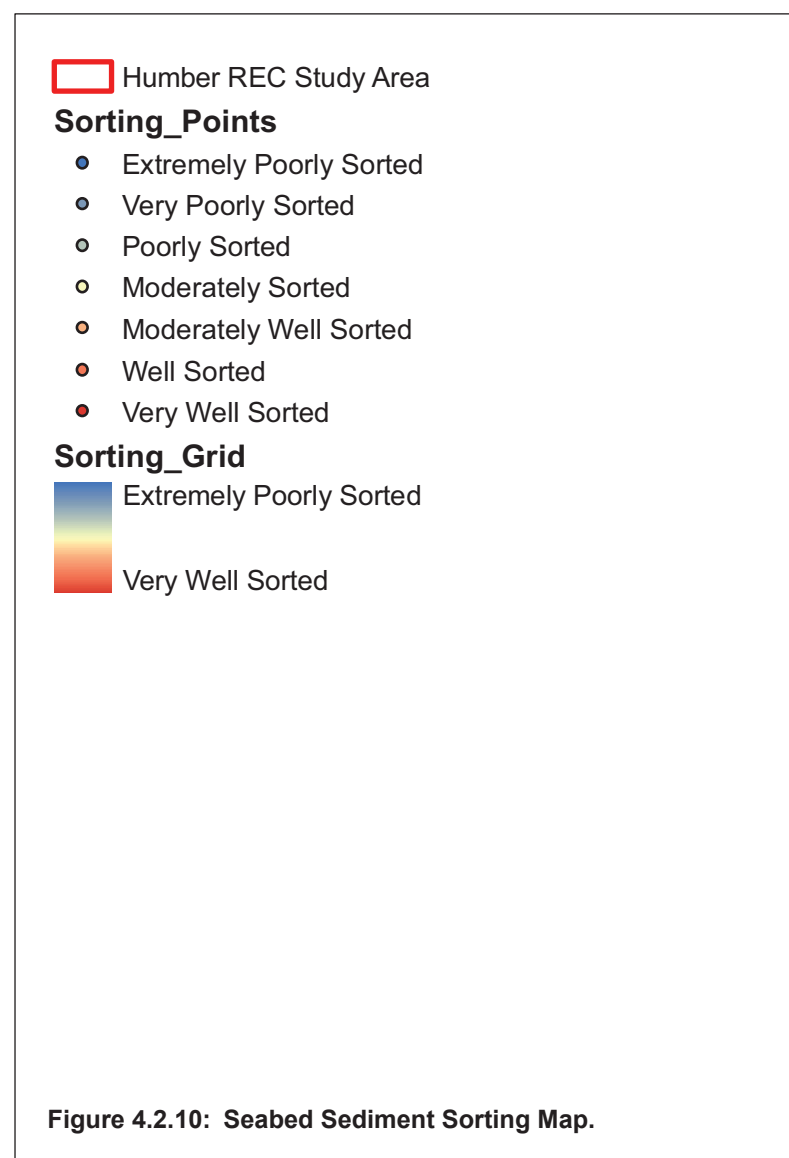
Finally, a Sea Bed Character map was constructed (Figures 4.2.7 and 4.2.8). This map is a very simplified visualisation of sea bed sediment distribution, and is derived from the new sea bed sediment map presented in Figure 4.2.3. It is based on Folk (1954) and the simplified classification was originally devised by Long (2006) to address the requirement of the EUNIS habitat classification (Connor *et al.* 2004). The methodology was further

modified by James *et al.* (2007) and James *et al.* (2010). The object of the classification is to identify the primary relationships between the sea bed sediment and the biotas present. The Folk classification scheme of 15 classes is used in the BGS offshore sea bed sediment maps and is a modified version of Folk (1954) devised by Pantin (1991) (Figure 4.2.3). The Sea Bed Character classification is based on four sediment classes (mud and sandy mud, sand and muddy sand, mixed sediment, and coarse sediment) and informs at level 3 of the EUNIS classification. In comparison to Folk, the boundaries between particle size fields have been adjusted so that the resultant sediment classes are

more accurate predictors of the distribution of biota, and therefore are better suited to defining distinctive biotopes.

The significant difference between Long, (2006) and James *et al.* (2010) is that the boundary between sand and muddy sand and mud and sandy mud is set at 6:1 (Sand:Mud). 'Mixed Sediment' now includes all sediment with between 30% and 80% Gravel, and 'Coarse Sediment' is > 80% Gravel. This habitat classification scheme has been applied to all REC grab samples and BGS legacy data, and forms the basis for the integrated assessment of habitats and biotopes which is discussed in Chapter 7. For this report, because of the common presence of large-scale





bedforms we have superimposed these on the simplified sediment distribution (Figure 4.2.8).

4.2.5 Other Sediment Character Maps

In addition to the maps above we also present distribution maps of sediment parameters:

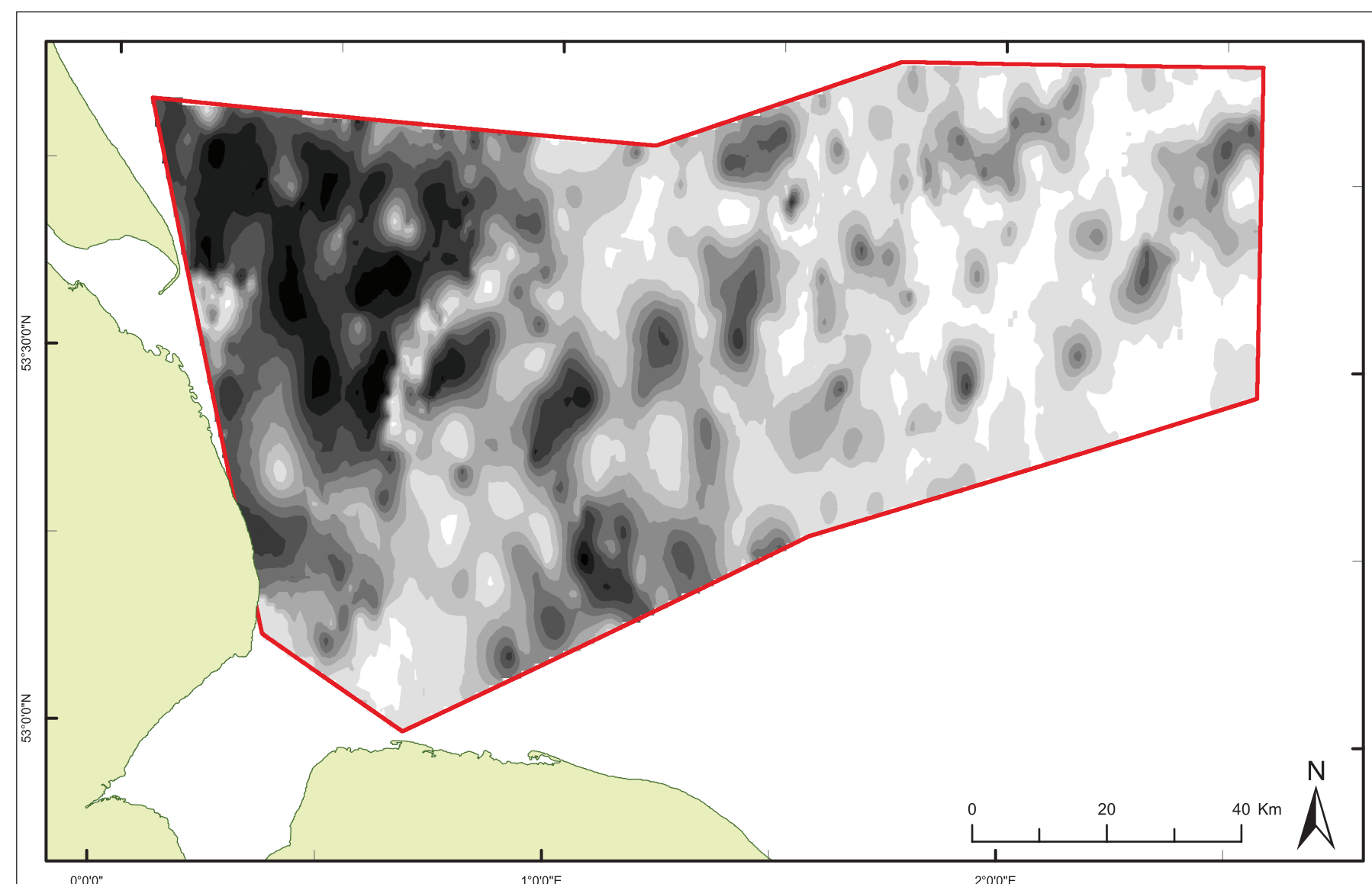
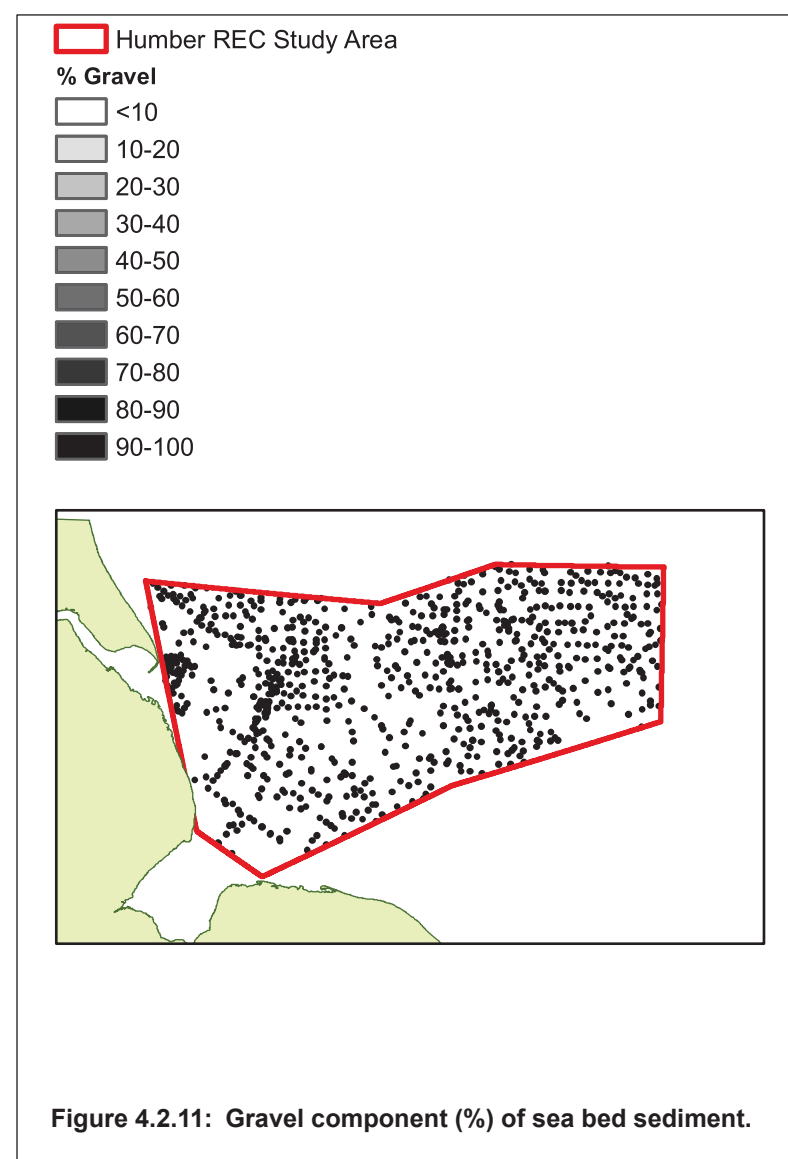
- Mapped sediment d_{50} (median grain size) (Figure 4.2.9). Gridded map based on Humber REC Hamon and Clamshell grabs, as well as BGS legacy data. Results are necessarily

more accurate for the sand fraction, as half-PHI analysis was only done on the sand fraction of the samples. d_{50} was calculated using GRADISTAT (Blott and Pye, 2001). d_{50} for the gravel and mud is therefore based on a linear interpolation of the particle size curve, which in turn is based on relative percentages of mud/sand/gravel (half-phi on the sands).

- Mapped sediment sorting (Figure 4.2.10). Gridded sorting map based on Humber REC Hamon and Clamshell grabs, as well as BGS legacy data. The sorting index reflects the variance in grain

size within a particular sample. The sorting value was calculated using GRADISTAT (Blott and Pye, 2001).

- Mapped gravel distribution (%) (Figure 4.2.11). Gridded maps of percentage gravel, sand, and mud are based on particle size analysis of the Humber REC Hamon and Clamshell grabs, as well as BGS legacy data.
- Mapped sand distribution (%) (Figure 4.2.12),
- Mapped mud distribution (%) (Figure 4.2.13).



4.3 Geological Interpretation

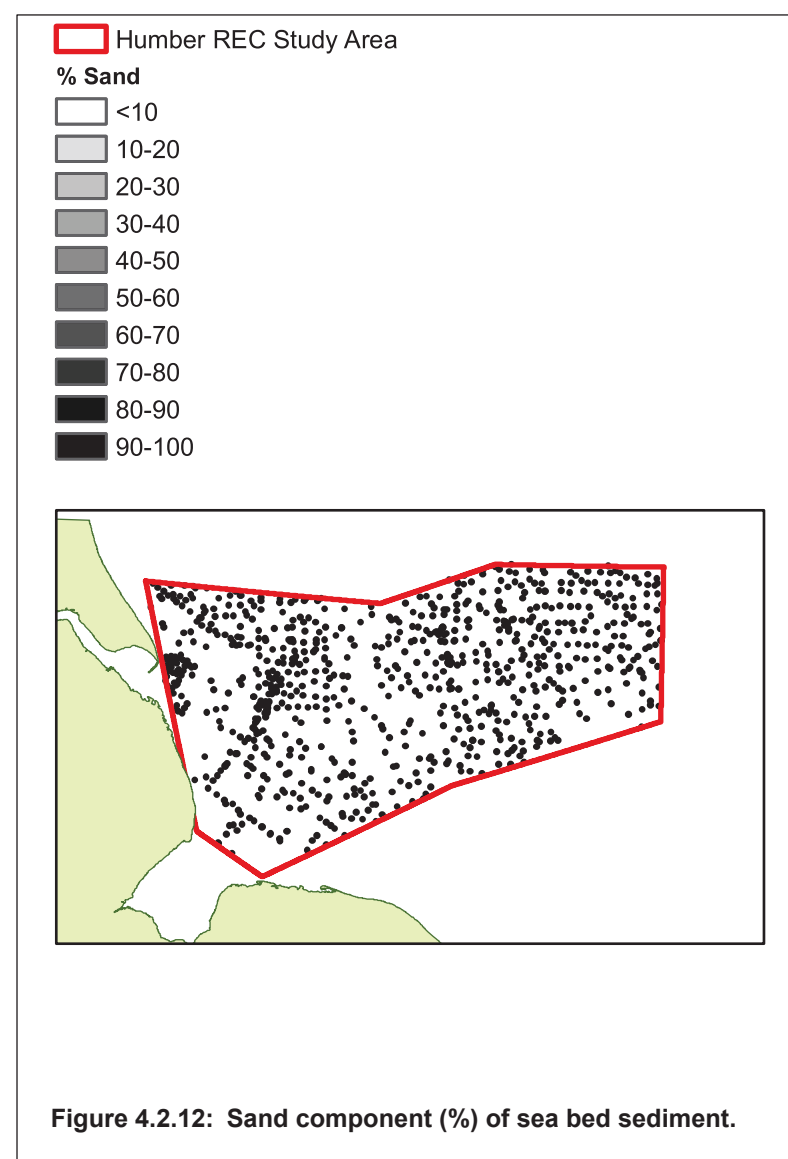
The first results of the geological interpretation (summarised in Chapter 2), carried out for the Desk Based Report (Tappin *et al.* 2009) were based on published papers, reports and BGS maps that predate digital data acquisition and MBES and SeaZone bathymetry. They were based on integration of analogue 2D seismic and point-source sample data, with the data compiled as hard copy and the maps drafted by hand.

For this report our interpretations also use the existing BGS legacy data, but are augmented and improved by the newly

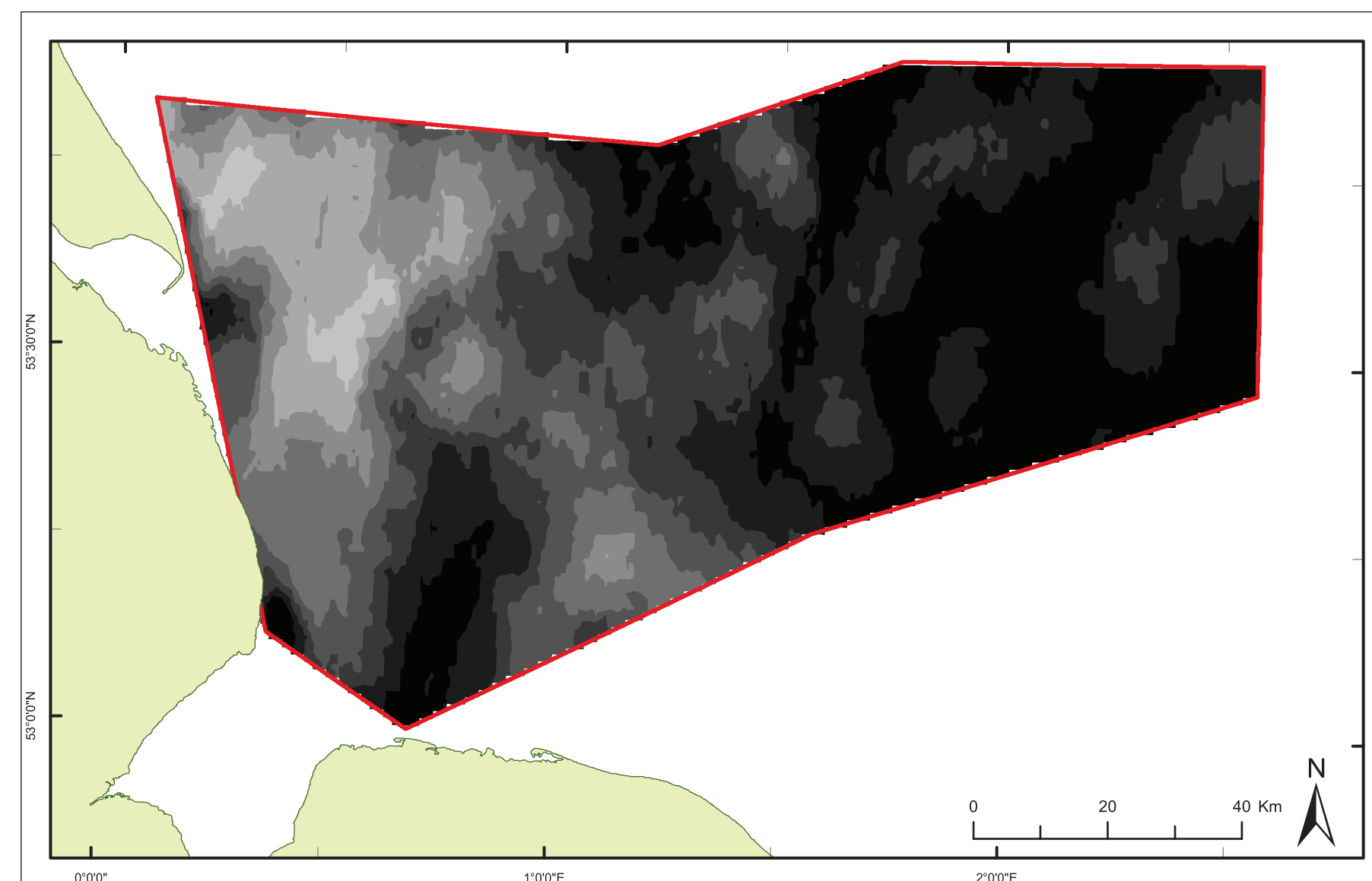
acquired REC survey and SeaZone data. All the data available, both legacy and REC, were uploaded onto an ARC GIS database, which was viewed and manipulated in a single, geographically referenced space, enabling a fully integrated interpretation of the Humber REC area. In addition, we created a virtual 3D sea bed in Fledermaus, to view and interpret sea bed morphology in a detail not previously available (Figures 4.2.1 and 4.2.2). Not only is sea bed morphology visualised, but draping sea bed sediment distribution onto the SeaZone bathymetry allows direct comparison between the sediment distribution and the bathymetry (compare Figures 4.2.3. and 4.2.4). Importing the high resolution geophysical

data (MBES, Sidescan Sonar and Boomer) into Fledermaus allows 3D visualisation of the architecture of the small-scale sea bed morphology.

As with other RECs (Emu Ltd, 2009; James *et al.* 2010) we reviewed the geological and geophysical data to determine whether there were distinctive elements of the physical environment, such as seabed morphology, geology and/or sediment distribution that would characterise particular geographic areas to distinguish them from each other. This would allow the different areas to be compared and contrasted and lead to an improved understanding and presentation of their interpretation. In the instance of the



Humber REC, however, there were no major elements in the area on which to base a meaningful subdivision. There are indeed geographical variations in some data, for example sea bed sediment distribution. But, alternatively, there are also many major features, such as the deeps and the sand banks that are present over the whole area. Using one feature as a basis for subdivision would therefore lead to a false impression of the distribution and commonality of others. It was decided that any geographical subdivision of the geology into regions or zones would be artificial and misleading. We therefore describe the area on the basis of its major morphological, geological, and sedimentary components.



In consideration of the biology however, we have identified three zones based on sediment distribution: Humber West, Humber Central and Humber East (Figure 4.2.8). Humber West is mainly gravelly. Humber Central is a transition zone between the mainly gravelly west and the sandy east, but with extensive areas of sandy sea bed; it has similarities to both the bordering zones. Humber East is dominantly sandy.

4.3.1 Bedrock and Pleistocene Geology

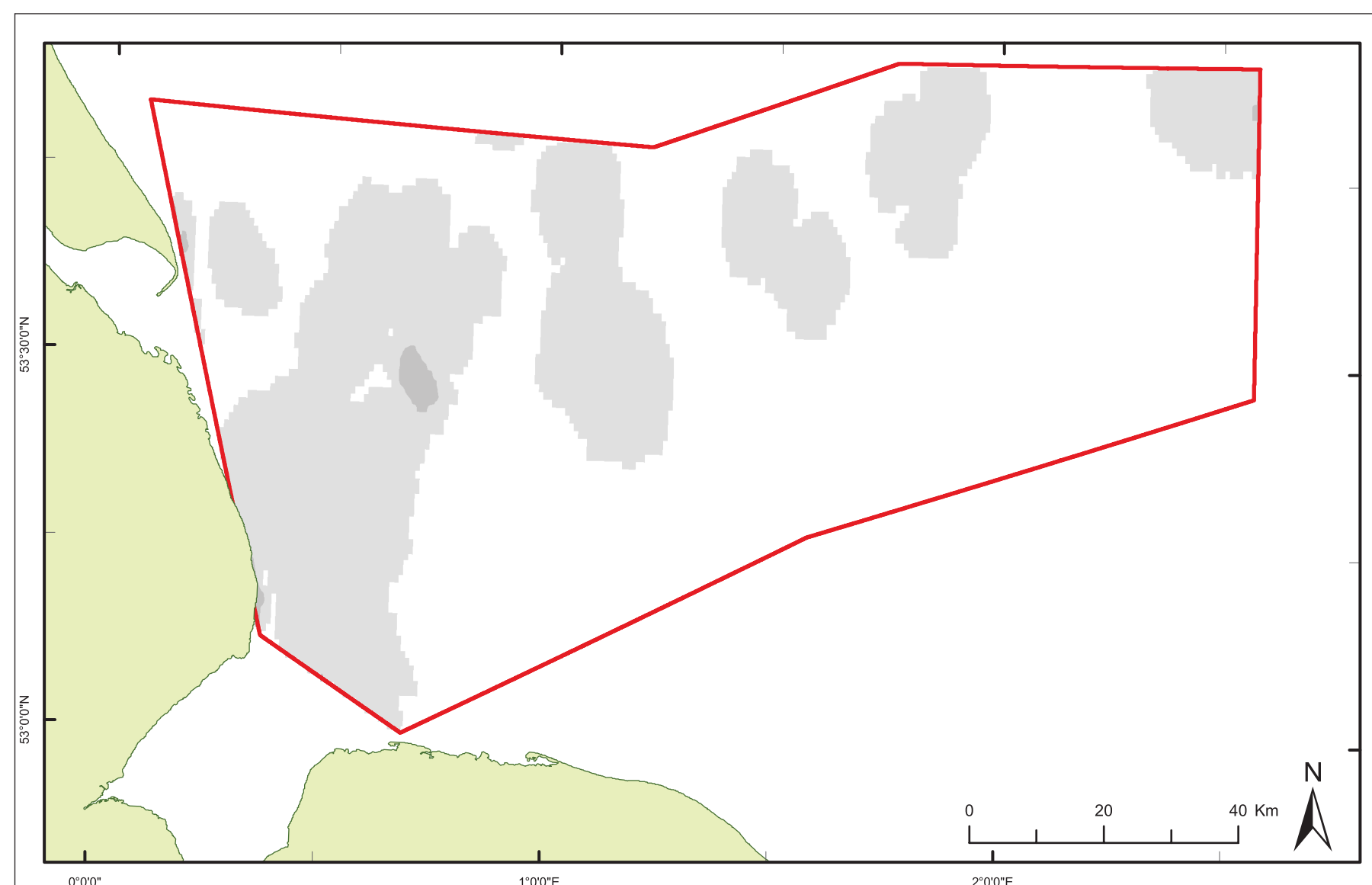
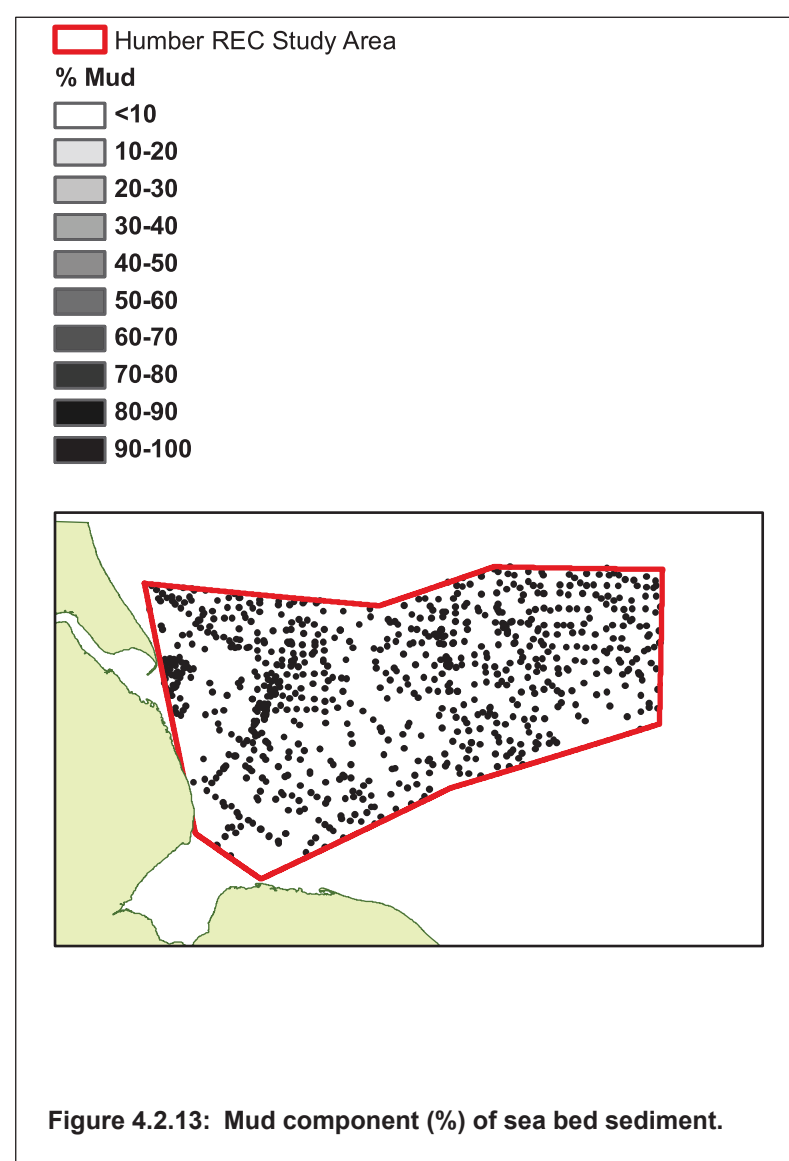
Because of the blanket of Holocene sediment, bedrock and Pleistocene deposits are only exposed at sea bed in the deeps. Thus there are few areas where the pre-Holocene is exposed at sea bed.

Bedrock

In the deeps the area of exposed bedrock has been remapped and its extent amended (Figures 4.2.6, 4.2.14 and 4.2.15). BGS legacy data shows that bedrock is Cretaceous chalk in the Silver Pit and Jurassic clastics in Sole Pit (Figures 4.2.14 and 4.2.15). There are further sea bed exposures of chalk in the small linear deep to the west of the Inner Dowsing Shoal (Donovan, 1972), although BGS data does not reveal this.

Mid-Early Pleistocene

Only on the flanks of the deeps and in the southeast of the REC area are sediments of the early and mid-Pleistocene age exposed



at or near seabed (Figure 2.3.2). Exposed at sea bed in the deeps are Swarte Bank, Sand Hole, and Egmond Ground formations in the Silver Pit and the Yarmouth Roads and Winterton Shoal formations in Sole Pit (Figures 4.2.14, 4.2.15). In the southeast, the older Pleistocene sediments subcrop the Holocene sediment cover. These older units are the Yarmouth Roads, Swarte Bank, Egmond Ground, and Sand Hole formations (Figure 2.3.2). There has been no new mapping of these formations.

Late Pleistocene — Bolders Bank Formation

Over most of the Humber REC area there is a significant hiatus between the mid-Pleistocene, Egmond Ground Formation and the

late Pleistocene Bolders Bank. Only in the far east of the area have Ipswichian interglacial sediments been identified; preserved in lows associated with the Swarte Bank channels. Egmond Ground is an interglacial deposit of the Hoxnian and Bolders Bank was laid down during the Devensian glaciation; so glacial deposits of the Wolstonian are completely absent in the Humber REC area.

The Bolders Bank Formation is present over 90% of the REC area and underlies a variable thickness of Holocene sediment (Figures 2.3.2, 2.3.3). It is only absent in areas of the deeps and in the southeast. There are, however, some locations where it is at sea bed (see below). The Formation is generally between 10 and 20 m

thick and mainly composed of stiff boulder clay, with interbedded coarse sediment — boulders and gravel. The REC boomer data confirms the thickness and distribution of the Formation as mapped previously (Cameron *et al.* 1986; Tappin, 1991). Recent research (Carr, 1999) on the micromineralogy of the Boulders Bank till indicates that it is of subglacial origin, so mapping the geographical extent of the Formation allows reconstruction of the likely geometry of the LGM ice sheet in the Southern North Sea. The mapped southern extent of the Bolders Bank Formation lies just to the south of the Humber REC area except in the southeast where it crosses it. Thus, it seems likely that the Humber REC area lies at the southernmost limit of the Devensian ice sheet. In addition

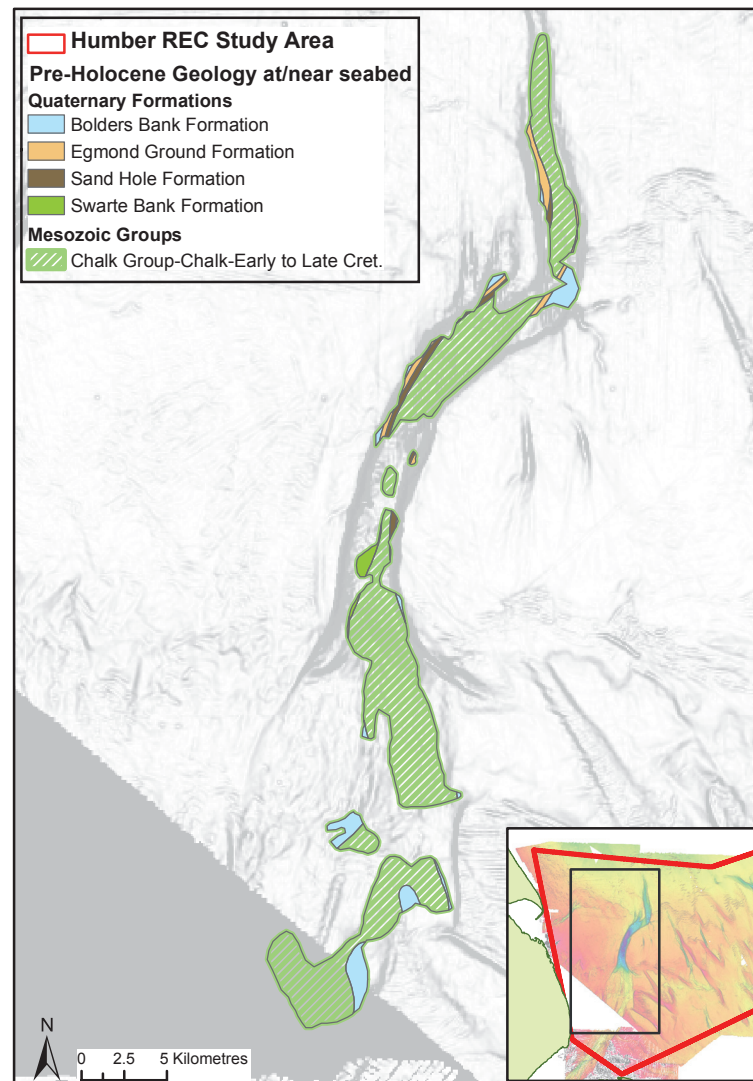


Figure 4.2.14: Exposure of pre-Holocene geology at or near the seabed in the Silver Pit and associated glacial outwash plain.

to providing evidence on ice sheet extent, research on clast concentrations from cores within the Bolder Bank till suggests that its' thickness has not been significantly reduced since deposition. Only one metre of thickness was removed during the Holocene marine transgression (Carr, 1999). The pocked surface of the till (Figure 4.2.16) suggests *in situ* clay dissolution.

Late Pleistocene — Botney Cut Formation

The Botney Cut Formation forms channels incised into the Bolders Bank till and a new map of its distribution is presented

(Figure 4.2.17). Channels are present over most of the REC area. They are up to 80 m deep and up to 5 km wide (Figure 4.2.18). Their morphology varies. In the east the channels are broad and discrete, almost scaphiform or boat shaped, and similar to the deeps. In the west they are mainly narrow and anastomosing. The variations in channel morphology may be an artefact of the varying density of seismic lines. The REC seismic data over much of the area, even in combination with the BGS legacy data, is too widely spaced to map in detail the channel courses. The exception is in the west where there is a grid of boomer data with a line spacing of 4–5 km, that was acquired in 1990 (Harrison, 1992). This data set reveals the trend of the channels to be broadly NNW to SSE and in places anastomosing in form (Figure 4.2.18). The channel infill of the Botney Cut Formation, where present, varies. Some channels are sediment filled, others, such as Well Hole, are partially filled. On seismic data channel infill may be seismically stratified, indicating interbedded, probably fine-grained sediment (Figures 5.4.1 and 5.4.5). Samples show these sediments to be stiff tills at the base of the channels and soft muds nearer the surface (Cameron *et al.* 1992). At other locations the fill is chaotic or diffuse and indicates coarse-grained sediment (Figure 4.2.18). In many channels the seismic character indicates different phases of infill (Figure 4.2.18).

The radiating pattern and morphology of the Botney Cut channels is interpreted as due to their formation at the Devensian ice margin during the regional glaciation of the area (Cameron *et al.* 1992). Elsewhere in the North Sea similar channels, termed 'tunnel-valleys' have been identified at three stratigraphic levels in the Quaternary and interpreted as formed during the glacial episodes of the Anglian, Wolstonian and Devensian. Results from the Thames REC project reveal examples of Elsterian age farther south than previously known (Emu Ltd, 2009). The tunnel valleys of the two older glaciations are usually (but not always) sediment filled. Those of Anglian age are represented by sediments of the Swarte Bank Formation, that were formed either subglacially (Praeg, 2003) by rivers under high hydrostatic pressure and subsequently infilled by sediment, or by catastrophic outbursts of meltwater from the collapse of ice dammed lakes (Wingfield, 1990; Huuse and Lykke-Andersen, 2000); the so-called 'jökulhlaup'.

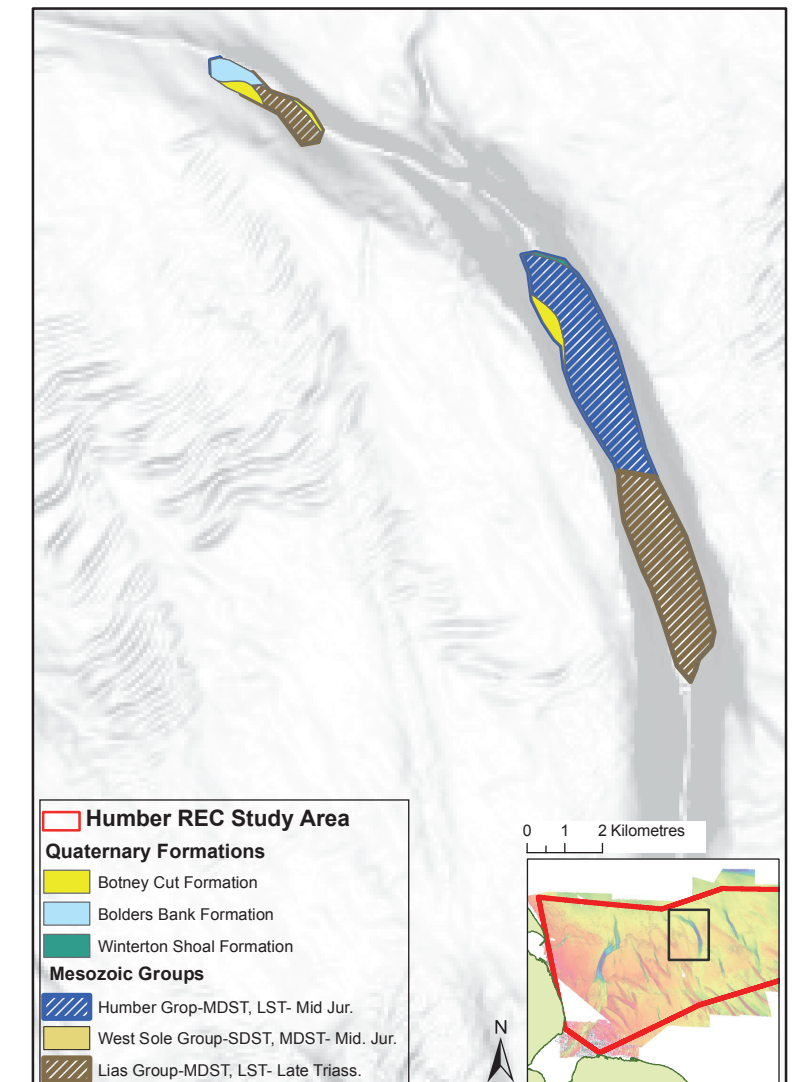


Figure 4.2.15: Exposure of pre-Holocene geology at or near the seabed in the Sole Pit.

Of the two theories on formation of the tunnel valleys Praeg (2003), researching the Swarte Bank Formation, considered sub-glacial erosion and subsequent sediment back fill as the most convincing alternative. His conclusion was based on the time-transgressive formation processes of sub-glacial fluvial erosion and subsequent sediment backfill. Also, that the anastomosing channel character is hard to explain through catastrophic ice collapse and flooding. The size of the Swarte Bank channels, they are up to 500 m deep, 25 km wide and 10s of km long would require floods of significant size, and these Praeg (2003) also considered unlikely.

No analysis such as Praegs' (2003) has been carried out on the channels and sediments of the Botney Cut Formation, thus the study of the Swarte Bank Formation may not be entirely relevant. The Botney Cut channels are much smaller than those of the Swarte Bank, with maximum depths of 80 m and channel widths of up to 5 km. The difference in scale may be due to the location of the Botney Cut Channels on the margins of the Devensian ice sheet, where the ice thickness was relatively thin compared to that of the Elsterian ice in the same area (Cameron *et al.* 1992). However, the similarity in channel morphology (anastomosing channels) and the presence of stiff tills at their bases suggests a mode of formation similar to that Swarte Bank; cut subglacially with a number of phases of subsequent sediment infill; initially sub-glacially and later under post-glacial conditions, when the upper level softer sediments were deposited. There is no doubt however, that the variation in the morphology of the Botney Cut channels and the deeps at seabed, as well as their various sediment infills, presents some problem as to interpreting their origin. This is discussed in Section 4.3.1 below.

4.3.1 Major Sea bed Morphology

On the broad scale, the SeaZone data, gridded at 60 and 100 m, reveals the complexity of the regional sea bed morphology (Figures 4.2.1 and 4.2.2). The most outstanding morphologic features are the enclosed deeps and sand banks that are superimposed on a gently undulating sea bed with a regional gradient inclined to the north and northwest.

The Deepes

The deeps, from Sand Hole in the west to Markham's Hole in the east, form a pattern radiating southward (Figures 4.2.1, 4.2.2). The most prominent are the Silver and Sole pits. Silver Pit is the largest at 38 km long 2.5 km wide, 100 m deep and deepest at 60 m below the surrounding seabed (Figure 4.2.19). It bisects the region and almost cuts off the area to the east. Sole Pit is somewhat smaller at 34 km long, 2.5 km wide and 80 m deep. Both have marginal slope gradients of up to 12°.

Both the Silver and Sole pits are remarkably curvilinear (Figures 4.2.1, 4.2.2 and 4.2.19), with marginal channels entering at inflexions on their flanks. The smaller deeps, such as the Outer Dowsing Channel, are mainly linear. They are orientated mainly NNW–SSE and like the larger deeps are boat-shaped and

U-shaped in cross-section, with steep (7–10°) flanks. They extend farther to the south, to 53°S, than the large deeps. A number are offset en echelon along their length; for example in the east two deeps extend south of Well Hole, in which direction they are successively offset to the east (Figure 4.2.20). An offset is also seen in the deep to the west of the Outer Dowsing Shoal (Figure 4.2.2).

On most of the deeps, such as Sand Hole for example (Figure 4.2.19), channels enter their ends. The most significant channel, a system in fact, is located at the southern end of Silver Pit and extends southward towards the Lynne Deepes and the Wash (Figures 4.2.1, 4.2.2, 4.2.19 and 4.2.21).

In the Humber REC area, the deeps are mainly incised into the Bolders Bank Formation, although in places erosion may expose strata down to bedrock. In the Silver and Sole pits the erosion exposes bedrock at seabed (Figures 4.2.14 and 4.2.15). In Silver Pit, Chalk strata with a strike of ENE–WSW are well defined on the MBES and the boomer data (Figure 4.2.22). In Sole Pit, Jurassic is exposed either at seabed, or beneath a thin sediment cover. Some deeps are partially filled with sediment.

Focussed Surveys

Detailed biological surveys were carried out in the Silver and Sole pits (Figures 4.2.23 and 4.2.24). These surveys are described in detail in Chapter 8, but a brief description is included here. The base of the Silver Pit has a sandy cover, but this is generally thin and in places bedrock is exposed (Figure 4.2.6). The area of focussed survey Bio 1 reveals the variety of bedforms that may be found in such a small area (3 km by 1.5 km) (Figure 4.2.23). The sediment cover is generally thin at the base of the deep, with slope failure and small sand waves on the flanks. Hummocky sea bed may reflect the presence of glacial sediment, moraines for example. BGS legacy data indicates boulder clay to be present to the south of the survey area. The focussed survey area Bio 2, in Sole Pit, is 3 km by 1.5 km. Over most the area, bedrock is exposed at sea bed. In the northeast there are large-scale grooves that are probably due to ice scouring. Small-scale sand waves are present on the eastern flank of the deep.

Origin of the Deepes

The origin of the deeps has been subject to much debate. Valantin (1957) first proposed that they were of subglacial origin, and thus

formed as tunnel-valleys. Donovan (1972) suggested that they may be the product of tidal scour during post-glacial transgression. More recently, Wingfield (1990) proposed that older Quaternary 'incisions' were the result of catastrophic flooding from the collapse of glacial lakes at the ice margin; an explanation that might apply to the deeps. All explanations come up against some problem. If subglacially formed, as tunnel-valleys, they should display the anastomosing morphology typical of sub-glacial streams (Praeg, 2003); they do not. If formed by tidal scouring, there is no explanation as to why they should be radially arranged (and therefore apparently related to the Devensian ice-sheet margin). Why are some completely sediment free whereas others have a partial sediment infill? Why are some deeps linear and others, the larger ones, arcuate?

It seems that no one explanation fits all the evidence. It is too involved to discuss in detail here the various arguments on the formation of the deeps. However, based on the new interpretations of the REC data in the context of previously published work, the following observations on the deeps' origins are made:

- The deeps in the Humber REC area do not display the anastomosing pattern typically observed in tunnel-valley systems, suggesting they are not formed by exactly the same (glacial) processes,
- The different morphologies displayed by the deeps within the REC area, linear and arcuate, suggests too, that there may be different processes of formation for each different morphology,
- The greatest erosion depths (up to 100 m below present sea level and 60 m below sea bed) in the larger deeps indicates that they cannot have been cut solely by tidal scouring during Holocene transgression because at that time the gradient into the deeps from the adjacent seabed would not be of sufficient magnitude, and their enclosed nature would prevent sufficient current power to erode to these depths,
- In some deeps, the presence of glacial deposits, including boulder clay, and erosion features such as grooves that may be due to ice scouring, supports a glacial origin for some deeps,
- The relationship of certain smaller deeps, such as that west of the Outer Dowsing Shoal, is similar that found on the outer Norfolk Banks that are formed by tidal scouring,

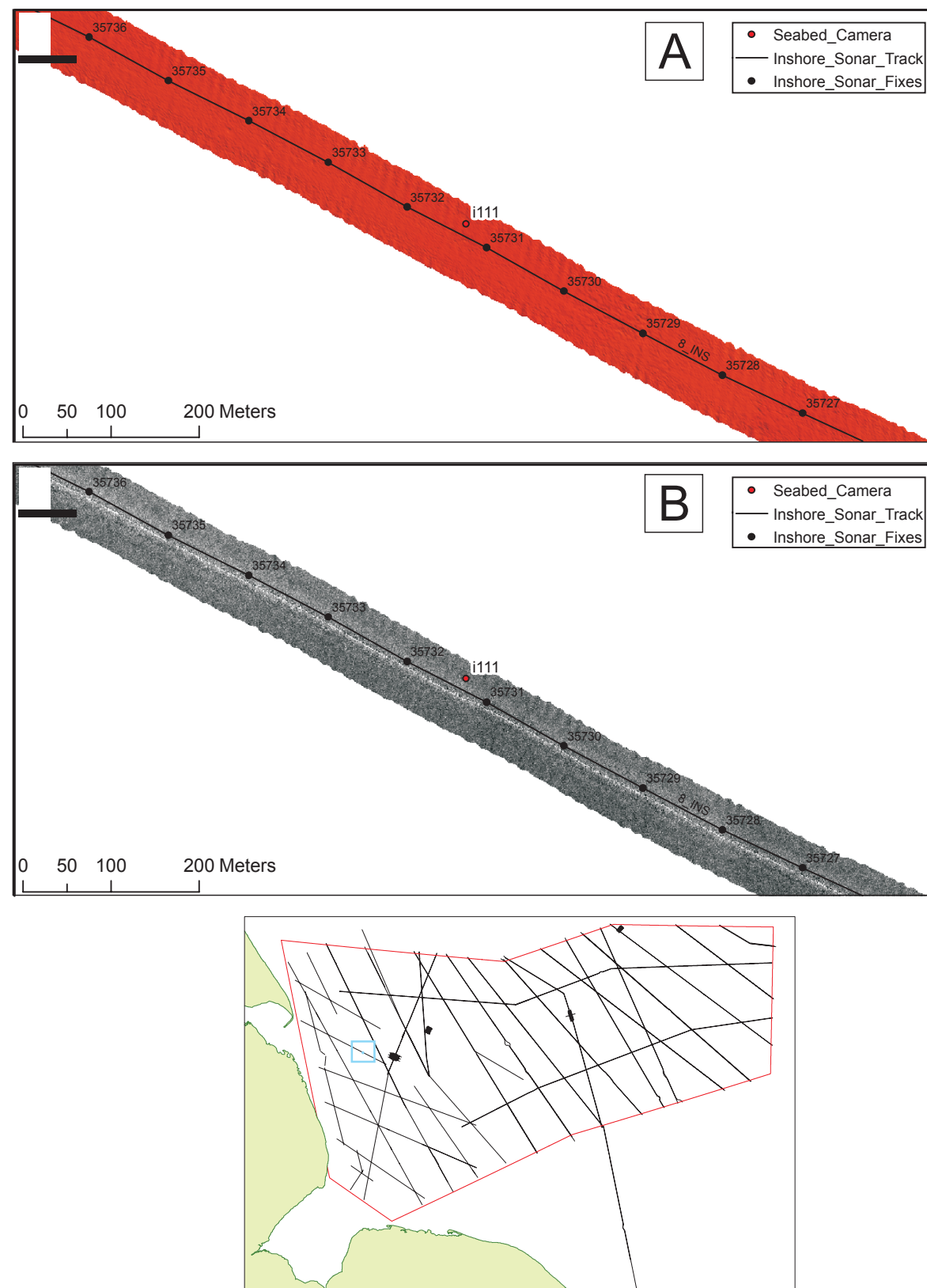
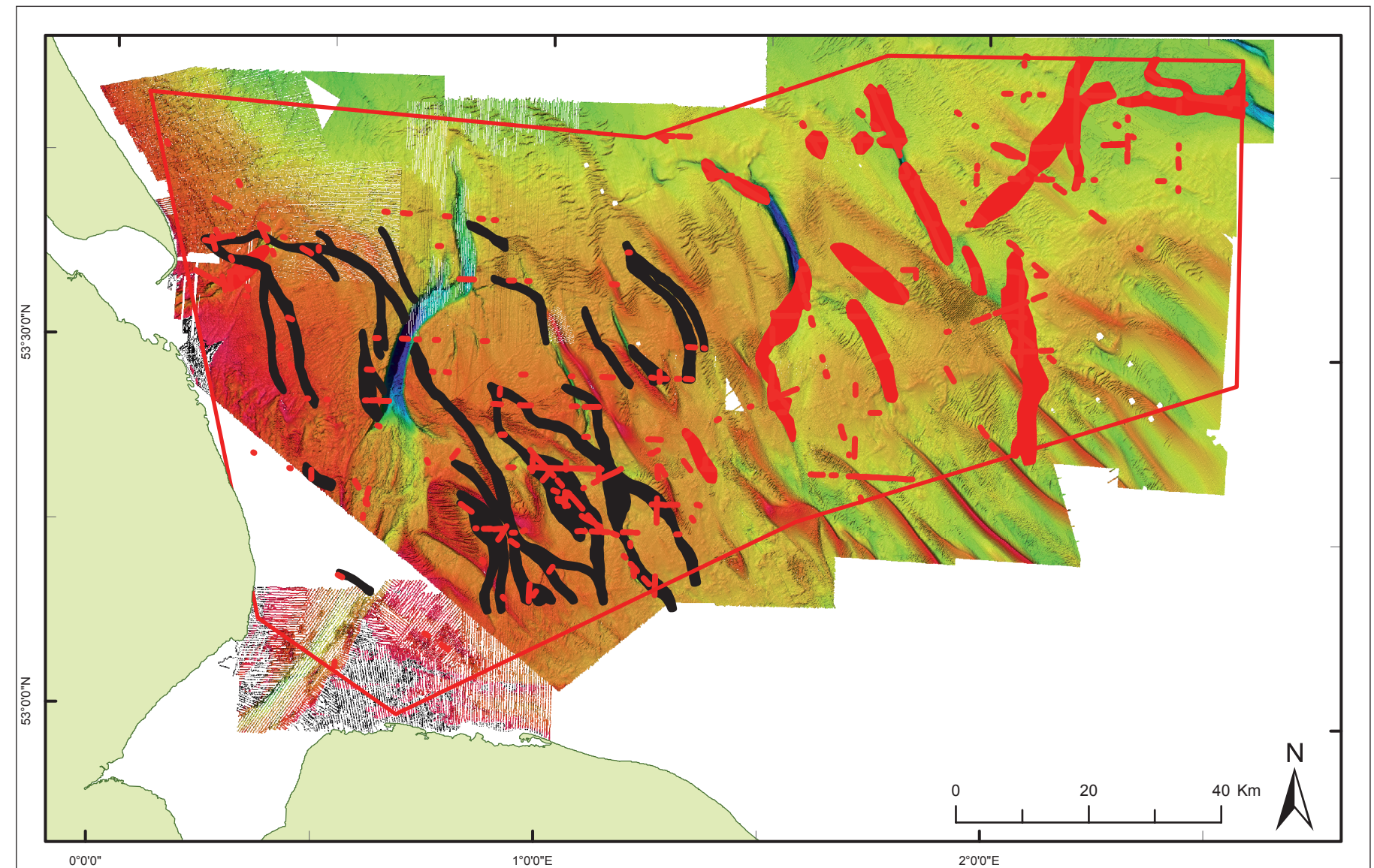


Figure 4.2.16: Thin or absent sediment cover over the boulder clay of the Bolders Bank Formation. A; MBES, B; Backscatter, C and D; seabed photographs of thin cobble layer on boulder clay.

- Humber REC Study Area
- Botney Cut Channel
- Harrison Channels (Botney Cut)
- Botney Cut New

Figure 4.2.17: Distribution of Botney Cut Channels overlaid on SeaZone bathymetry. 'Botney Cut Channel' mapped from BGS legacy and Humber REC geophysical data. 'Harrison Channels' (Botney Cut) modified from Harrison (1992). 'Botney Cut New' channels revised from Cameron (1986) and Tappin (1991). (Single beam echo sounder data © British Crown & SeaZone Solutions Ltd. Licence No. 052008.012. All rights reserved).



- The partial sediment infill of some deeps suggests that they may have been formed sub-glacially and then been eroded,
- Erosion of the sediment in the partially infilled deeps would have been post-glacial in age,
- The location of deeps such as the Silver Pit and Sand Hole in shallow water close inshore and morphologically connected to the Wash and Humber respectively, suggests that there is a genetic association,
- For Silver Pit, the above association in formation is supported by the channel at its southern end connecting to the Wash,

- During the lowered sea levels of the mid-Holocene, Sand Hole would have been on the coast and a channel through which the Humber drained,
- During the lowered sea levels of the mid-Holocene the Wash would have drained into the Silver Pit,
- Modern tidal currents are strong enough to transport sediment in the deeps (Pingree and Griffiths, 1979; Proctor *et al.* 2001), but whether of sufficient magnitude to erode lithified sediment and rock is unproven,
- During the rising sea levels of the Holocene transgression, tidal

currents would have been stronger than today, and almost certainly more focussed along lows in the transgressed topography,

- During the Holocene marine transgression the low topography of the southern North Sea together with the rapid rate of sea level rise of up to 20 mm/year (Behre, 2007) resulted in inundation rates of up to 100 m per year (Cooper *et al.* 2008).

The above list is not exhaustive, but it suggests that the formation of the deeps in the Humber REC cannot be explained by one single process. It is likely that their formation was polygenetic. Glacial processes led to the formation of some, if not all, deeps and

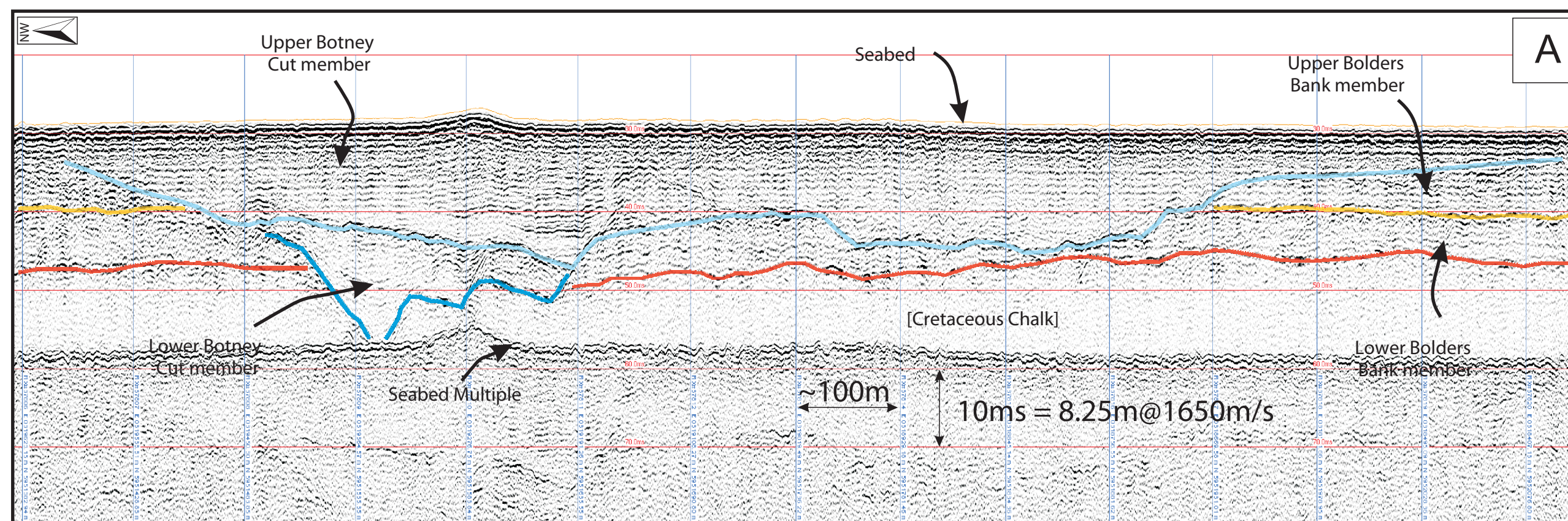
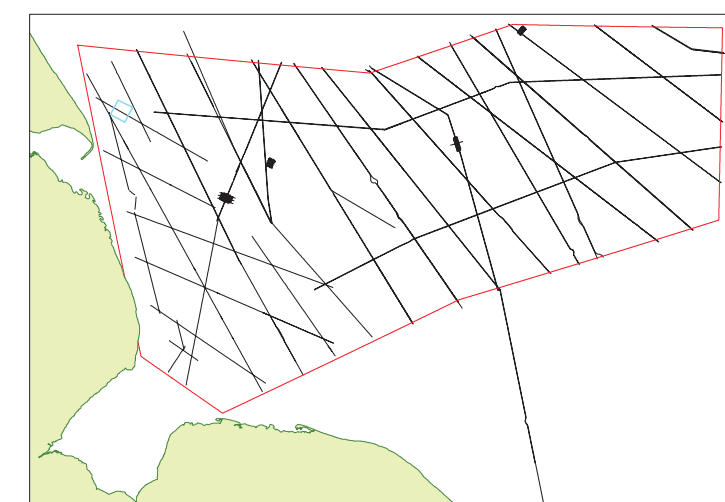


Figure 4.2.18: Representative seismic (boomer) line shows Botney Cut channels incising the Boulders Bank Formation and Cretaceous Chalk. See text for explanation.



for their infill as well. All deeps do not share the same evolutionary sequence. Once formed, their location was probably a major influence on subsequent evolution. For example, during lowered sea level, the deeps closer inshore may have had a genetic link to adjacent estuaries and rivers. The larger deeps probably evolved

through a more complex series of events than the smaller. Tidal scouring almost certainly removed some pre-existing sediment infill; it may also have had an erosive effect in deep formation too. The smaller, shallower, deeps may have been formed in the Holocene under marine conditions.

The Banks

The Banks form major positive features that cross-cut the area in a generally northwest to southeast direction (Figure 4.2.1 and 4.2.2). Their morphology varies from the planar, near shore Burnham Flats and Docking Shoal, through the (zig-zag) sinuous banks of Race

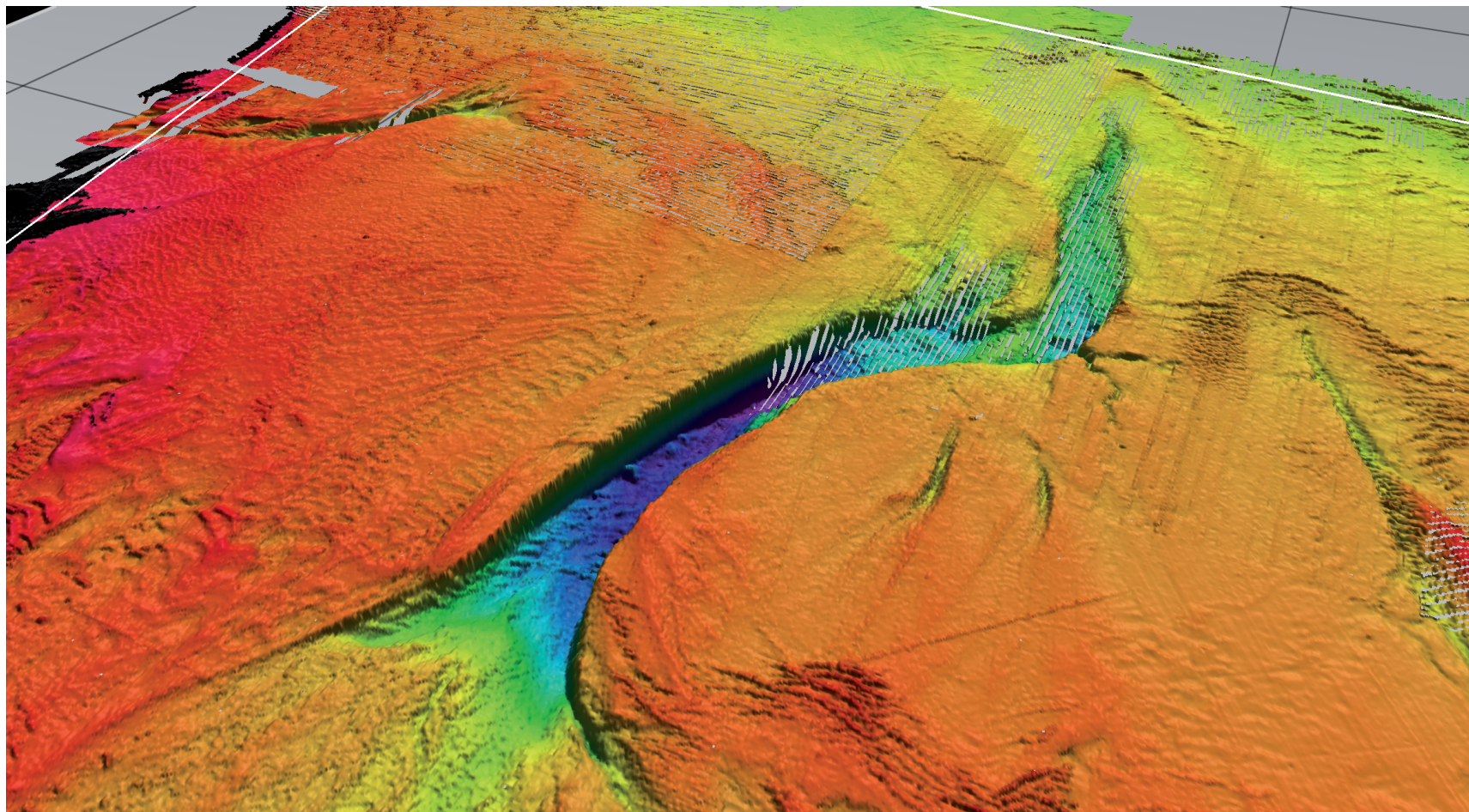


Figure 4.2.19: Bathymetry (60 m grid) of Silver Pit obliquely viewed from the southwest, with Sand Hole at left background (note channels entering from right hand side). (Single beam echo sounder data © British Crown & SeaZone Solutions Ltd. Licence No. 052008.012. All rights reserved).

Bank and Dudgeon Shoals to the terminations of the linear Outer Norfolk Banks in the east of the area.

The Burnham Flats and Docking Shoal are poorly imaged on the SeaZone data because of the wide line spacing of the single-beam echo sounder lines (Figures 4.2.1, 4.2.2 and 4.2.21). Water depths are shallow at less than 10 m and the seabed in these areas is mainly planar.

Race Bank, Dudgeon Shoal and Triton Knoll, are a series of sinuous, adjacent banks (Figure 4.2.1). They have planar bases and overlie the till of the Bolders Bank Formation. They are 15 to 20 km long, 1.5 to 3 km wide and stand at a maximum of about 10 m above the adjacent sea bed. Their crests are 5 m below Lowest

Astronomical Tide (LAT). They are asymmetric in form with their steeper, avalanche slopes facing to southwest, indicating sediment migration in this direction. Internal dipping reflections appear to confirm a south westward migration for the two banks (Cooper *et al.* 2008). BGS samples show the banks to mainly of gravelly sand with sand at the crest, although according to Cooper *et al.* (2008) they are formed of fine- to medium-grained sand. Race Bank is covered with east-west trending sand waves, 3 m amplitude with their steepest slope facing southward (Figure 4.2.25). Sand waves of similar amplitude on the un-named bank on the north flank of North Ridge are oriented WSW–ENE with their steeper flanks northward facing.

The Outer Dowsing Shoal and Cromer Knoll lie 10 km northeast of Triton Knoll. They are oriented NNW–SSE and form one main

morphologic feature 50 km long. They rise 5 to 6 m above the surrounding sea bed. As with the sinuous banks to the southwest, they are strongly asymmetric (steepest flanks) to the south west. A seismic record across the Shoal shows complex internal structure with possible movement to both the southwest and northeast (Cooper *et al.* 2008). The bank is composed of fine- to medium-grained sand and overlies the Bolders Bank with a planar base.

In the southeast of the Humber REC are the northern terminations of the Outer Norfolk Banks. The Banks are elongated roughly parallel to the modern coast and the tidal currents (Figure 4.2.1 and 4.2.2). They are asymmetric in profile with their steeper slope (up to 7°) facing towards the northeast (Figure 4.2.26). Well Bank is over 50 km long, 1.7 km wide and, in places, is elevated over 38 m above the surrounding sea bed. The shallowest waters on Swarte Bank (the deepest of the Outer Banks) are 9.6 m and over Ower Bank (the shallowest of the Outer Banks) 2.1 m at Lowest Astronomical Tide (LAT). In the Humber REC area the Banks have a relief of up to 20 m. Offsets and complexities are well displayed in Haddock and Indefatigable banks. There are numerous sand wave fields around the northern terminations of the banks and to the northwest (particularly in the east) they pass into areas of thicker sediment accumulations, some of which are covered in large-scale sand waves (Figure 4.2.26). The banks are entirely formed of sand and overlie a variety of substrates; Bolders Bank, Egmond Ground, Swarte Bank and Yarmouth Roads Formation. The Leman and Well Banks in some areas overlie early Holocene intertidal deposits. Their base may be planar, but some banks overly channels.

Internal reflections in the Banks dip to the northeast implying migration in this direction (Houbolt, 1968). As to whether the Banks are active or not is uncertain, although some evidence suggests that they may be. Caston (1972), from analysis of historic bathymetric charts, found that some of the more offshore Outer Norfolk Banks had elongated towards the northwest, the direction of net regional sand transport (Figure 2.4.3). Many of the Banks are covered in active sand waves, which reflect the pattern of the present sediment transport around them. Over their lower parts there are sand waves with crests aligned more or less at right angles to the bank crest, and with their steep faces in opposing directions on either side of the sandbank. This sand wave morphology reflects the dominance of clockwise circulation of sand around the bank (Collins, *et al.* 1995)

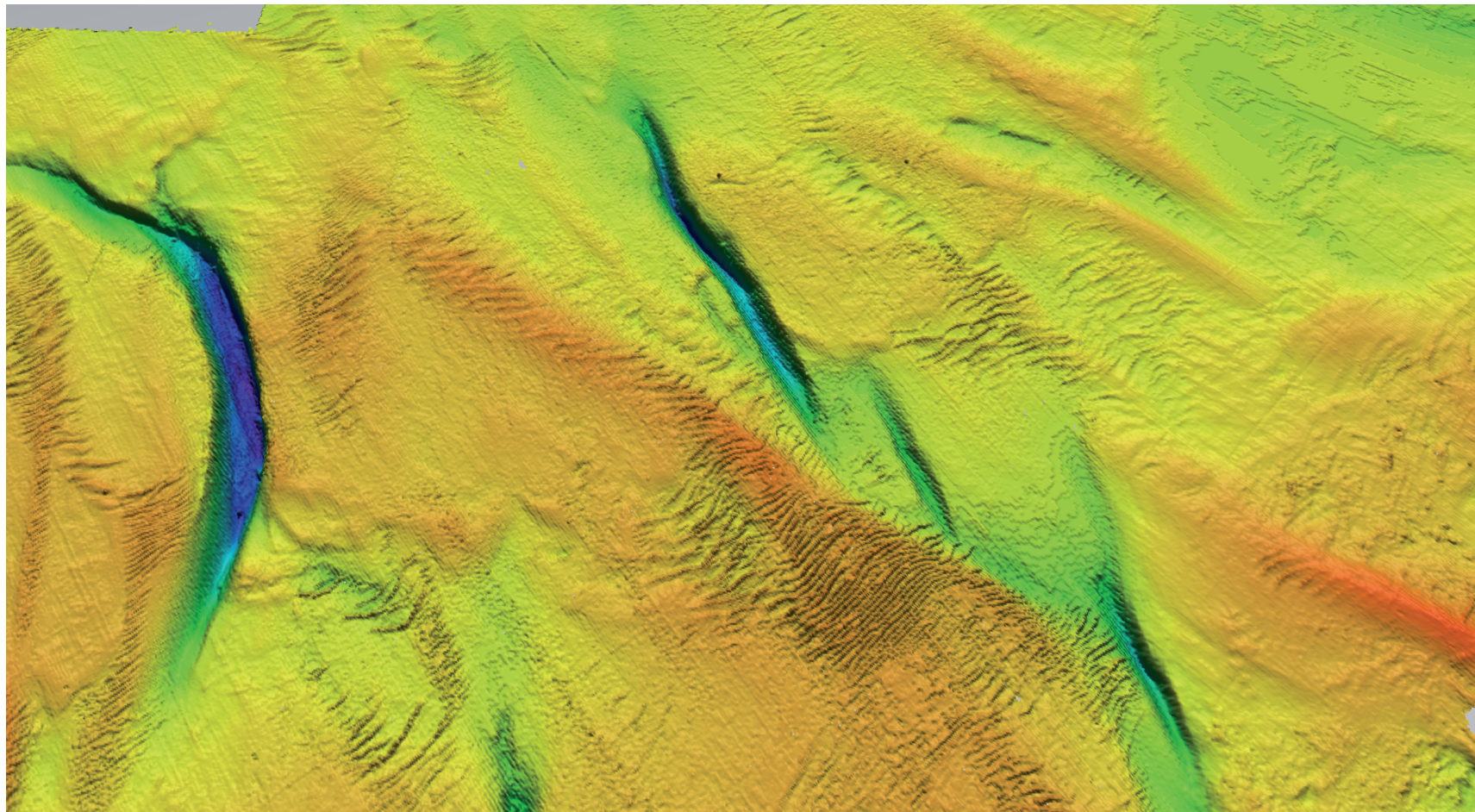


Figure 4.2.20: En echelon deeps of Well Hole (centre right). Sole Pit (left) and Well Hole (bottom centre) obliquely viewed from the south. (Single beam echo sounder data © British Crown & SeaZone Solutions Ltd. Licence No. 052008.012. All rights reserved).

that is active at present. Sand waves on the upper part of the flatter slope are directed more towards the crest, suggesting that the process that gave rise to the internal structure is ongoing, and that such features are indeed active.

Origin of the Banks

Groups of parallel banks such as the Outer Norfolk Banks are commonly found on open tidal shelves and are the largest bedform on the UK continental shelf (Kenyon *et al.* 1981). They are longitudinal and oriented parallel or subparallel to the dominant tidal flow. Most banks in plan view display wide upstream ends (heads) and narrow downstream ends (tails) (Caston, 1981). They commonly have a pronounced kink in the upstream direction. Their mechanism of formation was originally proposed by Zimmerman

(1981) and mathematically substantiated by Huthnance (1982). Field work by a number of researchers (Houbolt, 1968; Caston and Stride, 1970; Caston, 1972; Stride, 1974, 1988; Collins *et al.* 1995) confirm that the flows, sediment transport, bed geology, internal bank structure, bank morphology (length, side slopes, bank separation and angle of the bank crests to the tidal flow) and long-term movement of the banks all conform to his model.

Zimmerman (1981) proposed that with highly rectilinear flows, the bank crest forms at an angle to the flow that is accelerated up slope and decelerated down. In the northern hemisphere, for banks rotated anticlockwise to the flow, this results in Coriolis force and friction producing torques in the same direction so that the net circulation is reinforced and deposition takes place. For the Outer Norfolk Banks this mechanism of sedimentation explains their

5–20° anticlockwise rotation, in relation to the principal component of tidal flow and regional sand transport direction. The vertical growth of banks is limited by wave action, which tends to plane off the crest (e.g. Houbolt, 1968; Caston, 1972; Kenyon *et al.* 1981). In the instance of the Outer Norfolk Banks their origin is attributed to their location on the margin of a glacial outwash fan laid down by the Devensian ice sheet (Cooper *et al.* 2008). Their origin was thus the result of a location that was recently exposed to peri-glacial conditions and proximal to the large-scale sediment productivity from Devensian glaciation and glaciofluvial outwash. As sea level rose during the mid-Holocene transgression, this outwash sediment was reworked into the Outer Norfolk Banks.

The origin of the other banks (outside of the Outer Norfolk banks) in the Humber REC area has not been studied. It is considered likely, however, to be analogous to the formation of the Great Yarmouth Banks off of Norfolk because of their location adjacent to the coast and their similar morphology. The sinuous Race Bank and Dudgeon Shoal are similar to Haisborough Sand, Hammond Knoll and Hewitt Ridges that form the Outer Great Yarmouth Banks.

The Great Yarmouth Banks are considered to have formed as shore-attached banks that were progressively detached from a coast under retreat (Cooper *et al.* 2008), in a manner similar to the Shoal Retreat Massif of Swift (1975). The flood and ebb residual channels off the Inner Great Yarmouth Banks are consistent with the dynamics of a flood-ebb tidal meander channel that hugs the coast and is generated by a change in coastal alignment. In the instance of Norfolk, this change is where the east coast changes direction from north-south to east-west (see Figure 14 in Cooper *et al.* 2008). With continued coastal retreat the offshore banks progressively become relict features. Today the Inner Great Yarmouth Banks are active but the Outer Great Yarmouth Banks from Haisborough Sand to Smith's Knoll are relict features. They formed when the coast extended farther out to sea. As the Holocene transgression took place, and after formation of the Outer Norfolk Banks, the sea rapidly advanced towards the coast over a low topography. Across higher elevations, some distance north east of the present day coastline, the rate of transgression slowed and shoreline recession reduced dramatically. Rapid inundation was replaced by slower coastal erosion that sourced the sediment

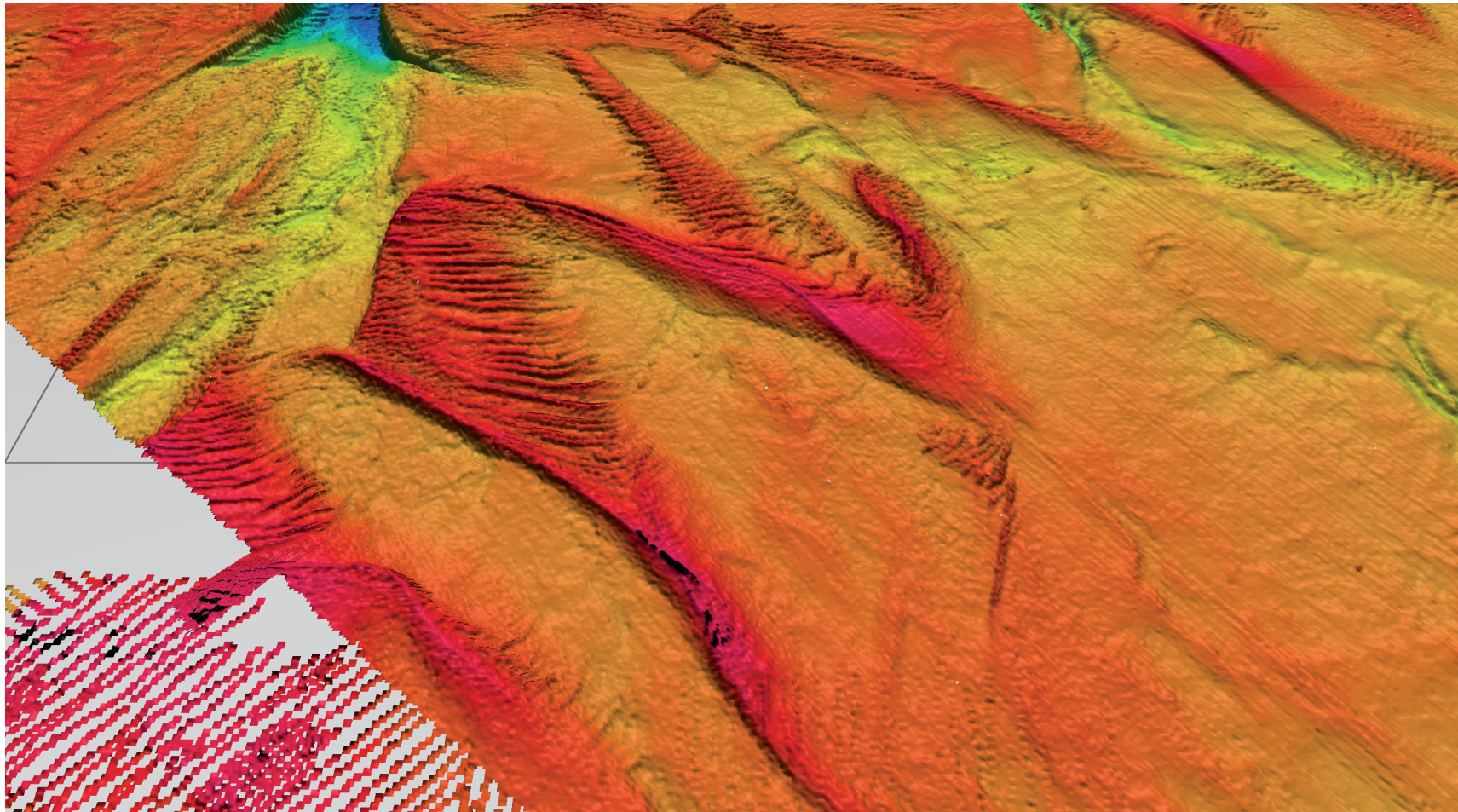


Figure 4.2.21: Race Bank in the foreground, Dudgeon Shoals behind, with the major channel feeding into Silver Pit (left) from the Wash. Obliquely viewed from the south. (Single beam echo sounder data © British Crown & SeaZone Solutions Ltd. Licence No. 052008.012. All rights reserved).

for construction of the nearshore banks. The Great Yarmouth Inner banks, therefore, formed after the Outer Norfolk Banks.

The hypothesis on the evolution of the area off Norfolk may be extended into the Humber REC area. It is based on the flooding of the Southern North Sea during the Holocene post-glacial transgression from Shennan *et al* (2000) (Figure 4.2.27). As sea level rose in this area, that extends northward to the Dogger Bank, the sea encroached from the south through a narrow seaway off of Norfolk (Shennan *et al.* 2000) (Figure 4.2.27b and c). First to flood was the area off Norfolk. The Outer Norfolk Banks formed first at 7 000 BP (Figure 4.2.27d), followed by the Outer Great Yarmouth Banks, probably by 6,000 BP. The Inner Great Yarmouth

Banks are much younger and formed at ~1 500 BP (Arthurton *et al.* 1994).

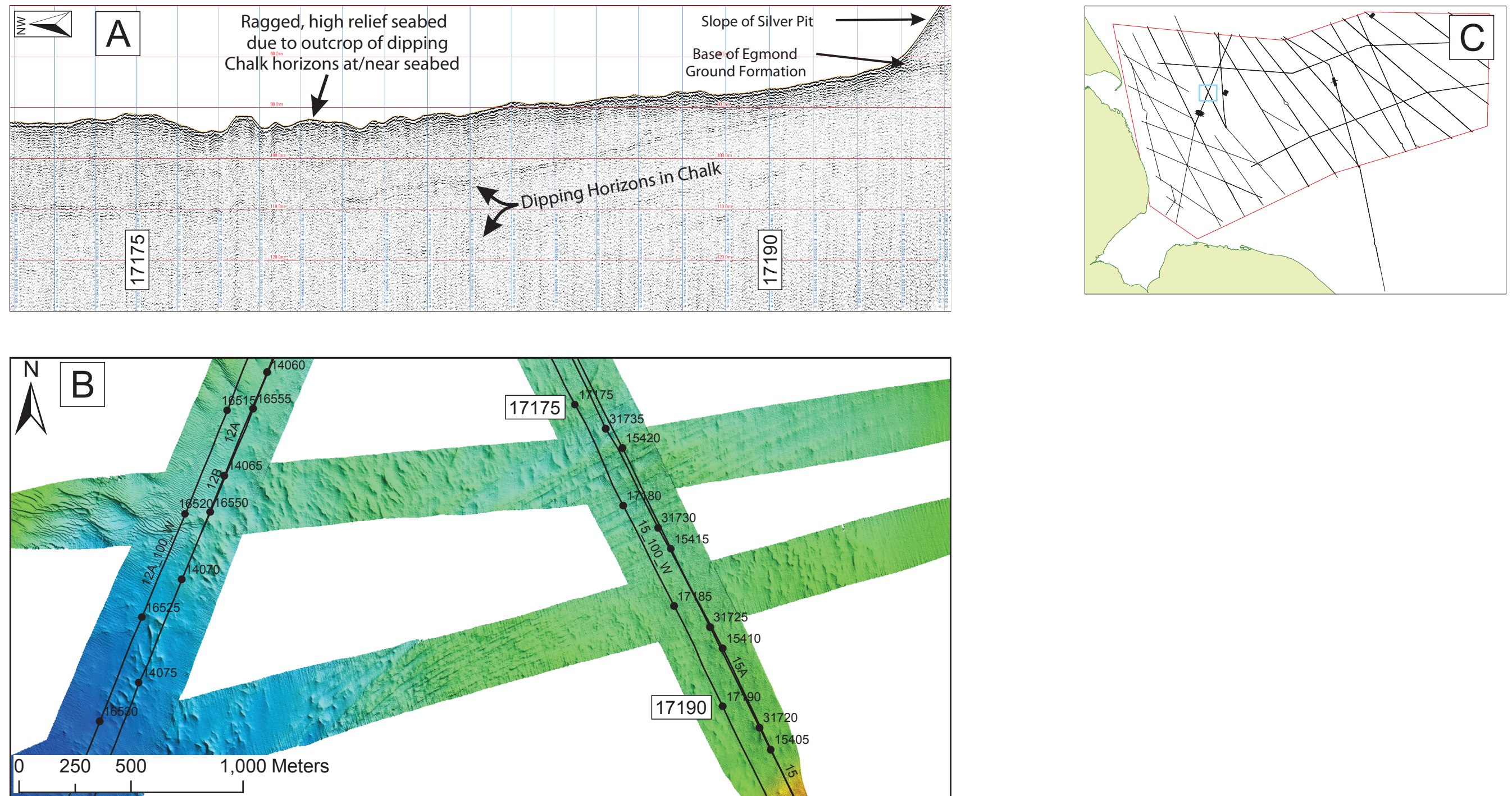
As marine conditions expanded into the Humber REC area, it is likely that as the area was transgressed the banks in the area seen today formed. The topography that was flooded is very different to that off Norfolk, so the sequence of events leading to bank formation is anticipated to have been different. The shape of the elevated coast line, with the deep embayment of the Wash and the proximity of Silver Pit, would have resulted in a complex current circulation that would have influenced sedimentation and bank formation (Figure 4.2.28). This topography may explain the dominance of southwest sediment transport that the bank

morphologies suggests. The Race Bank is now located 25 km offshore, but reconstructions by Shennan (2000) suggest that at 5000 BP the nascent Race Bank was adjacent to the coast. (Figure 4.2.28d). Formation of the sinuous banks through a flood-ebb tidal meander channel system is considered a distinct possibility. The formation of the outer banks from the Outer Dowsing Shoal northeastwards to Sole Pit may be analogous to that of the Outer Norfolk Banks. The volume of fine-grained sediment in the Humber region was probably not as great as that farther south. The cover of ice in the Humber REC area restricted deposition of finer-grained sediment, unlike areas farther south, where the main body of glacial outwash sand was laid down. Thus explaining perhaps the smaller size of the outer banks in the Humber compared to those of the Outer Norfolk Banks.

4.3.2 Sea Bed Sediment Distribution and Small-Scale Sea Bed Features

The new Folk sea bed sediment distribution (Figure 4.2.3) is broadly similar to the BGS maps published in 1987 and 1990 (Harrison *et al.* 1987; Balson, 1990) (Figure 2.3.5). However, correlation between the Folk sediment distribution from point-sourced samples and the sea bed morphology from the SeaZone and REC MBES and SSS data has resulted in modification of grain size boundaries to produce an improved map that reflects the relationship between the sediment and the large-scale bed forms present (Figure 4.2.4). One new observation is that the seabed sediment distribution is largely a reflection of the thickness of Holocene mobile sediment (sand) that overlies a gravelly pavement formed by winnowing of the boulder clay of the Bolders Bank Formation.

The REC geophysical data reveals a complex of bedforms and erosional features where sand, gravelly sand, and gravel may all be observed in a single 100 m patch. At this small scale, because there is not a regional coverage of MBES and SSS the sediment distribution cannot be mapped in detail across the area at survey scale. Thus, the sediment distribution map (Figure 4.2.3) is necessarily a map of bulk (majority component) sediment content. However, a clear regional distribution is identified of thicker Holocene sediments in the East, masking the underlying coarse-grained material which is more commonly exposed in the



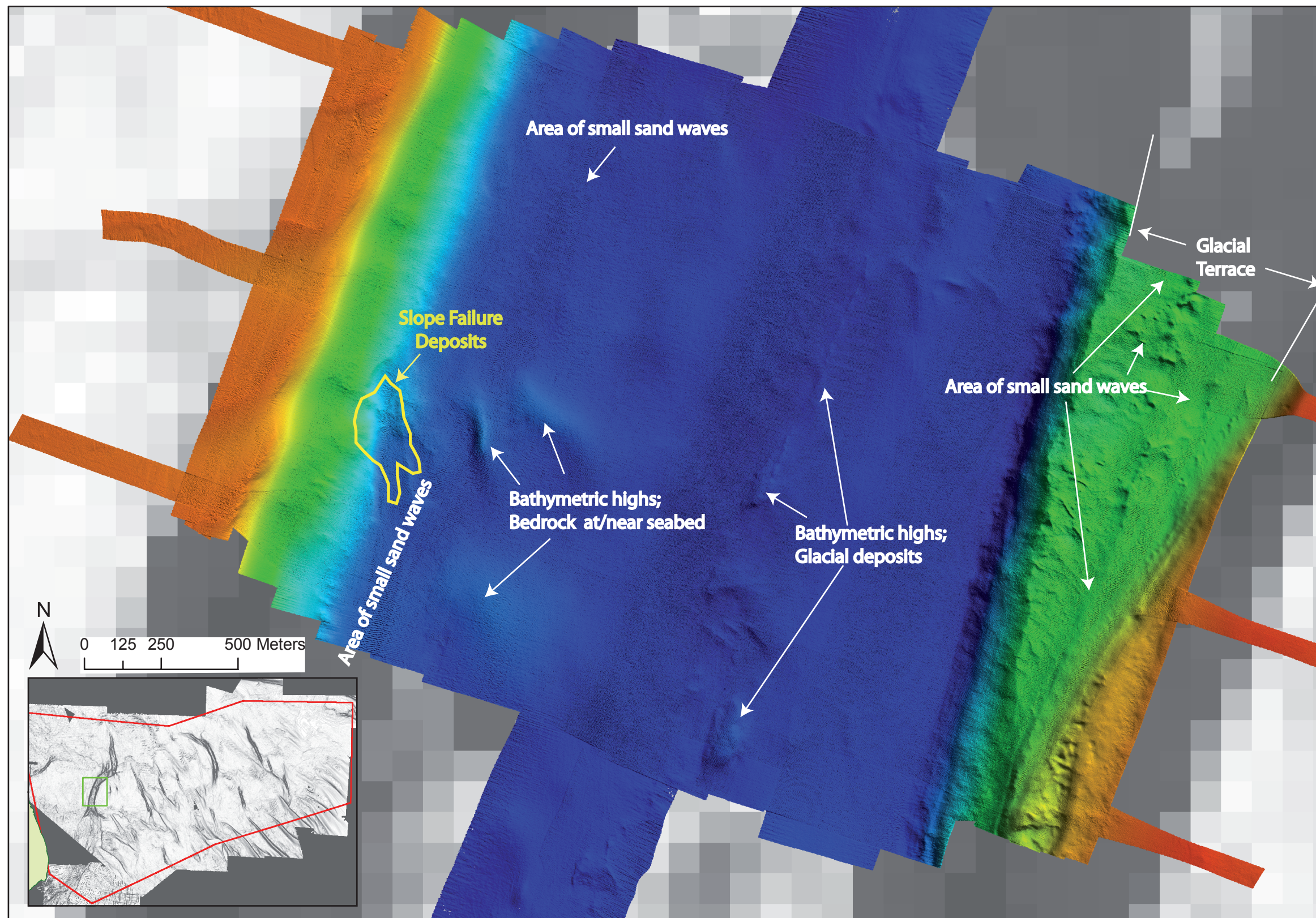


Figure 4.2.23: Seabed feature map within the BIO1 survey area within the Silver Pit. Bathymetry: MBES (1 m-colourscale) overlies a SeaZone (100 m-grayscale) backdrop. See text for explanation.

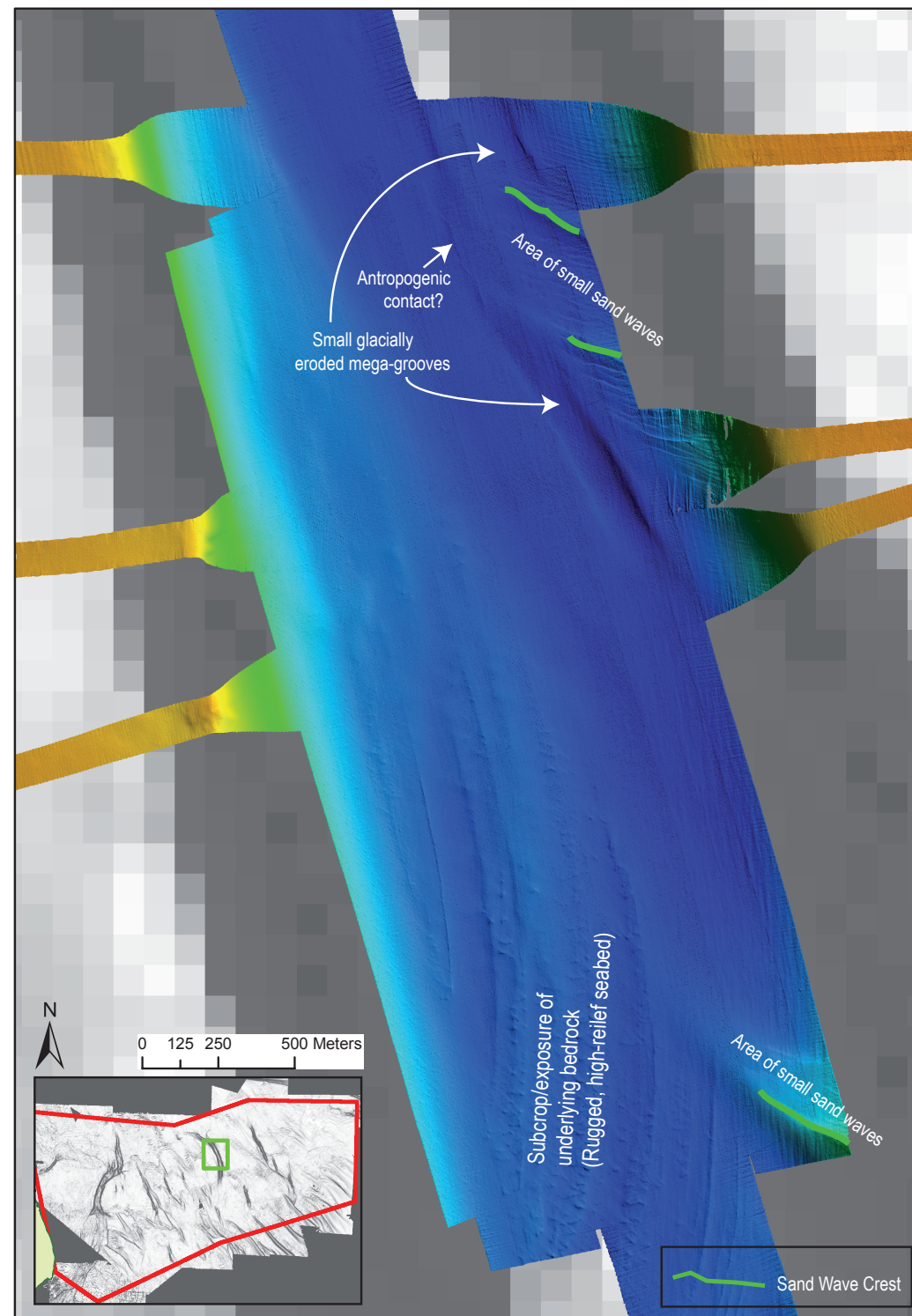


Figure 4.2.24: Seabed feature map of the BIO2 survey area within the Sole Pit. Bathymetry: MBES (1 m-colourscale) overlies a SeaZone (100 m-grayscale) backdrop. See text for explanation.

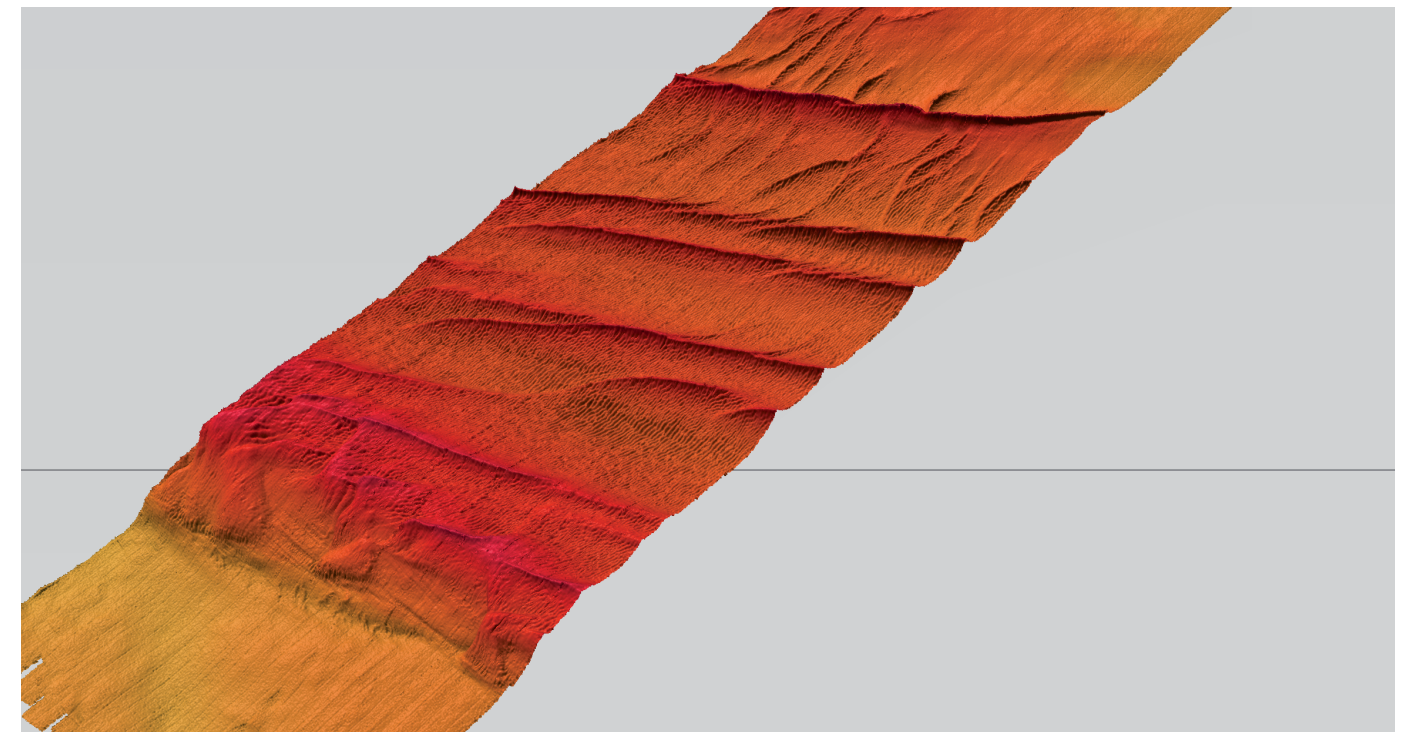


Figure 4.2.25: Oblique view of sand waves on the crest of Race Bank (SEA5 Survey data). See text for explanation.

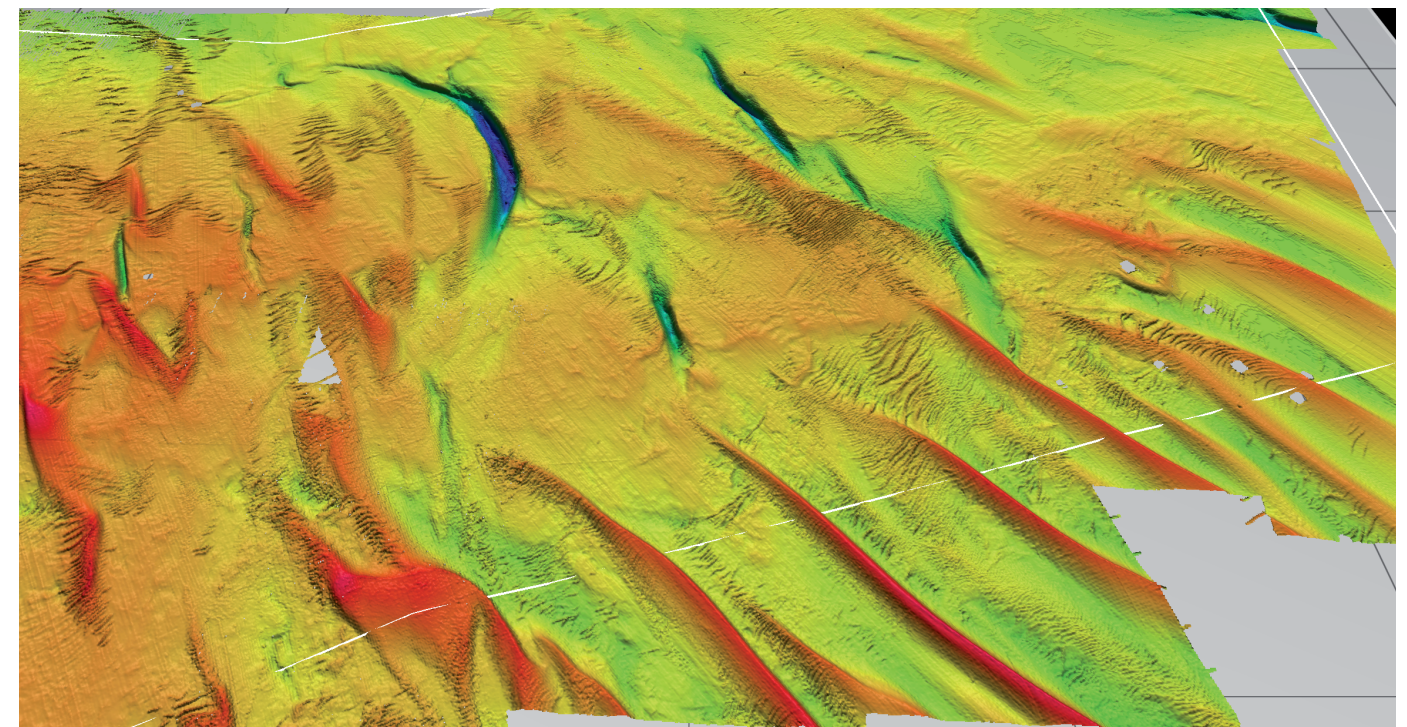


Figure 4.2.26: Norfolk Banks (in the foreground), viewed obliquely from the southeast. Note low amplitude banks to the northeast of the Norfolk Banks. Sole Pit and Well Hole in background. (Single beam echosounder data © British Crown & SeaZone Solutions Ltd. Licence No. 052008.012. All rights reserved).

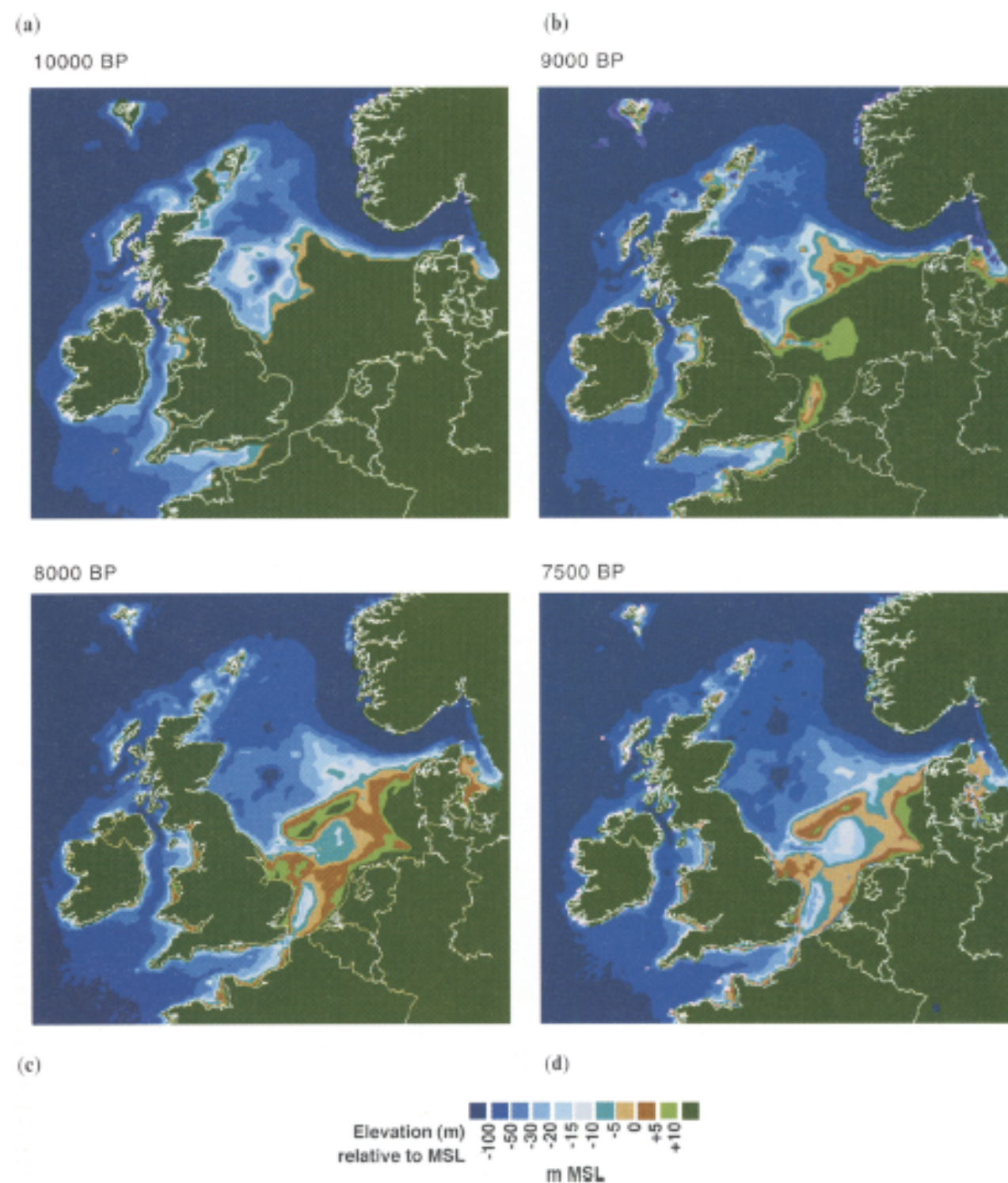


Figure 4.2.27: Palaeogeographic reconstructions of north-west Europe
(a) 10ka BP, (b) 9ka BP, (c) 8ka BP, (d) 7.5ka BP (from Shennan *et al*, 2000).

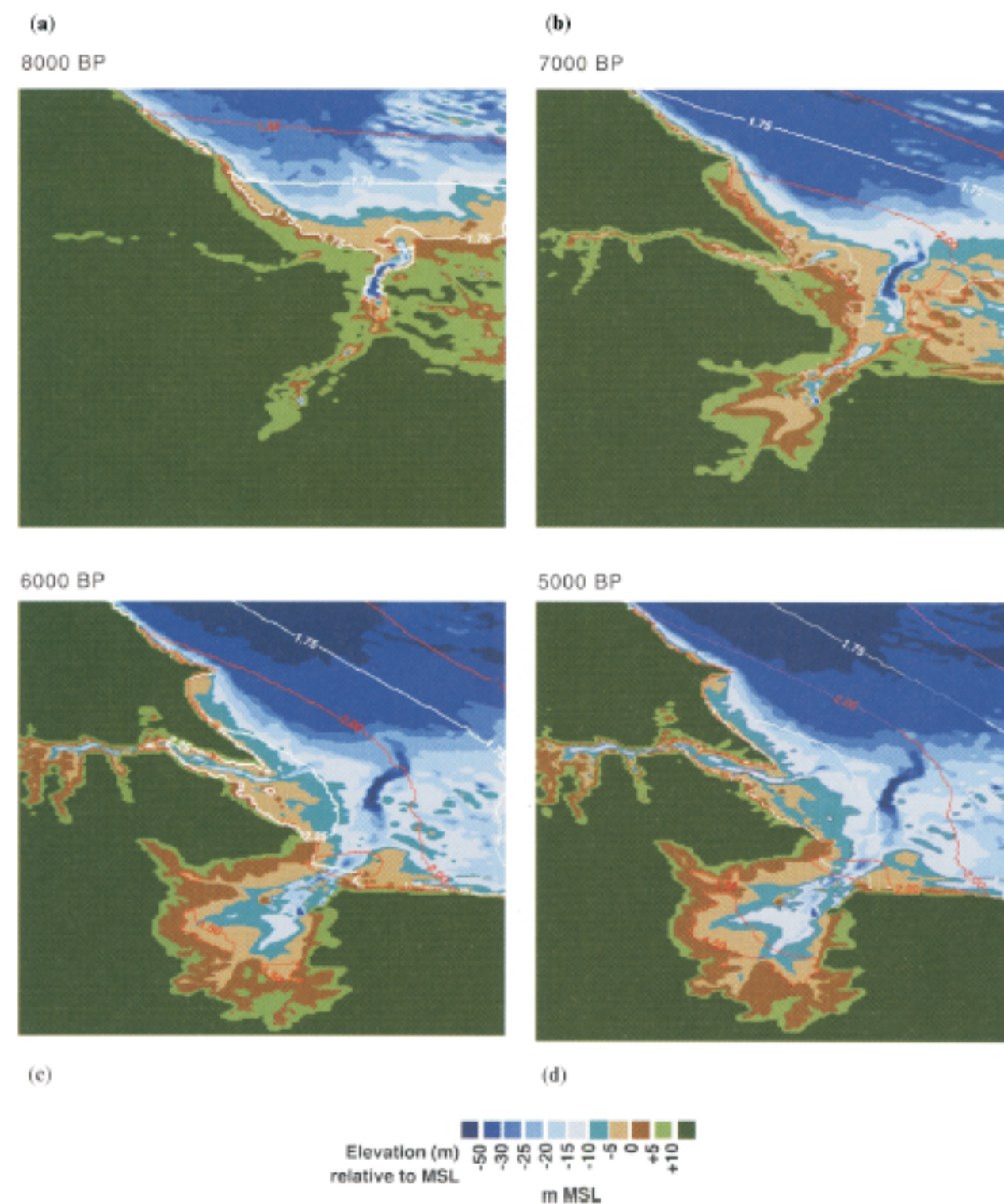


Figure 4.2.28: Palaeogeographic reconstructions and elevation for the southwest North Sea
at (a) 8 ka BP, (b) 7 ka BP, (c) 6 ka BP, (d) 5 ka BP (from Shennan *et al*, 2000).

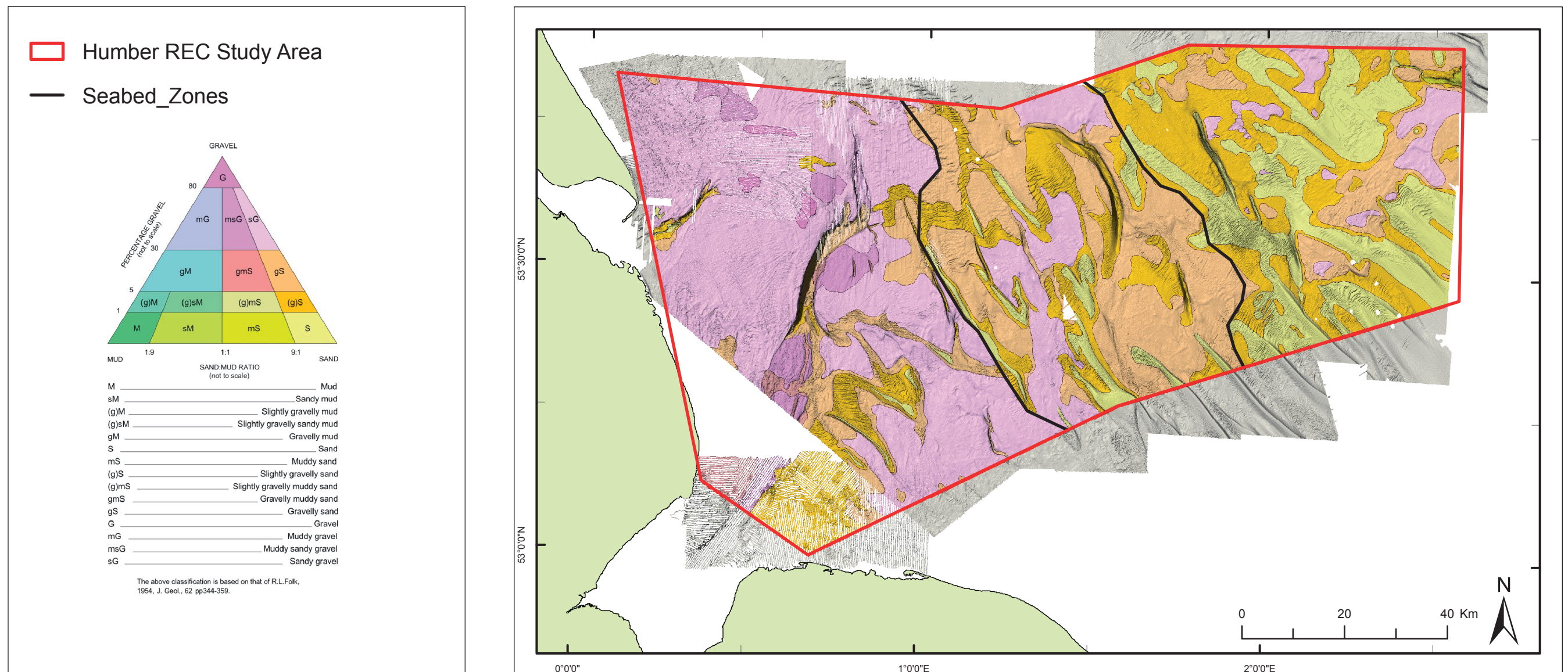


Figure 4.2.29: Sea bed zones based on the Folk seabed sediment distribution (draped on SeaZone data).
(Single beam echo sounder data © British Crown & SeaZone Solutions Ltd. Licence No. 052008.012. All rights reserved).

West. It is this distribution that largely causes the regional fining of sediment towards the east, exemplified by the overall Folk sediment distribution, together with the distribution %gravel, %sand, and %mud (Figures 4.2.11, 4.2.12 and 4.2.13) and d_{50} (Figure 4.2.9). The sediment is predominantly coarse-grained (sand to gravel) with only one area of mud in the northeast in Markham's Hole. Sediment is mainly gravelly in the west and sandy in the east, with a transitional area of mixed sediment between.

As noted previously, based on sediment distribution, three zones are recognised, with gravelly sediment prevailing in the west, sandy sediment in the east and a mixed region in between (Figure 4.2.29). Sedimentary features common to these three zones are sand banks and larger sand waves as well as smaller sea bed features such as small sand waves and flutes and grooves.

4.3.2.1 The Gravelly West

In the west, large areas of seabed are covered with gravelly sand (Figures 4.2.3, 4.2.4 and 4.2.6). There are also small areas of gravel and muddy sandy gravel located on the northern margins of Silver Pit and the channel at its southern end. Away from sand banks the sediment cover is generally thin (less than one metre) (Figure 4.2.6). In numerous BGS shallow cores, red-brown tills of the Boulders Bank Formation underlie a thin sediment cover

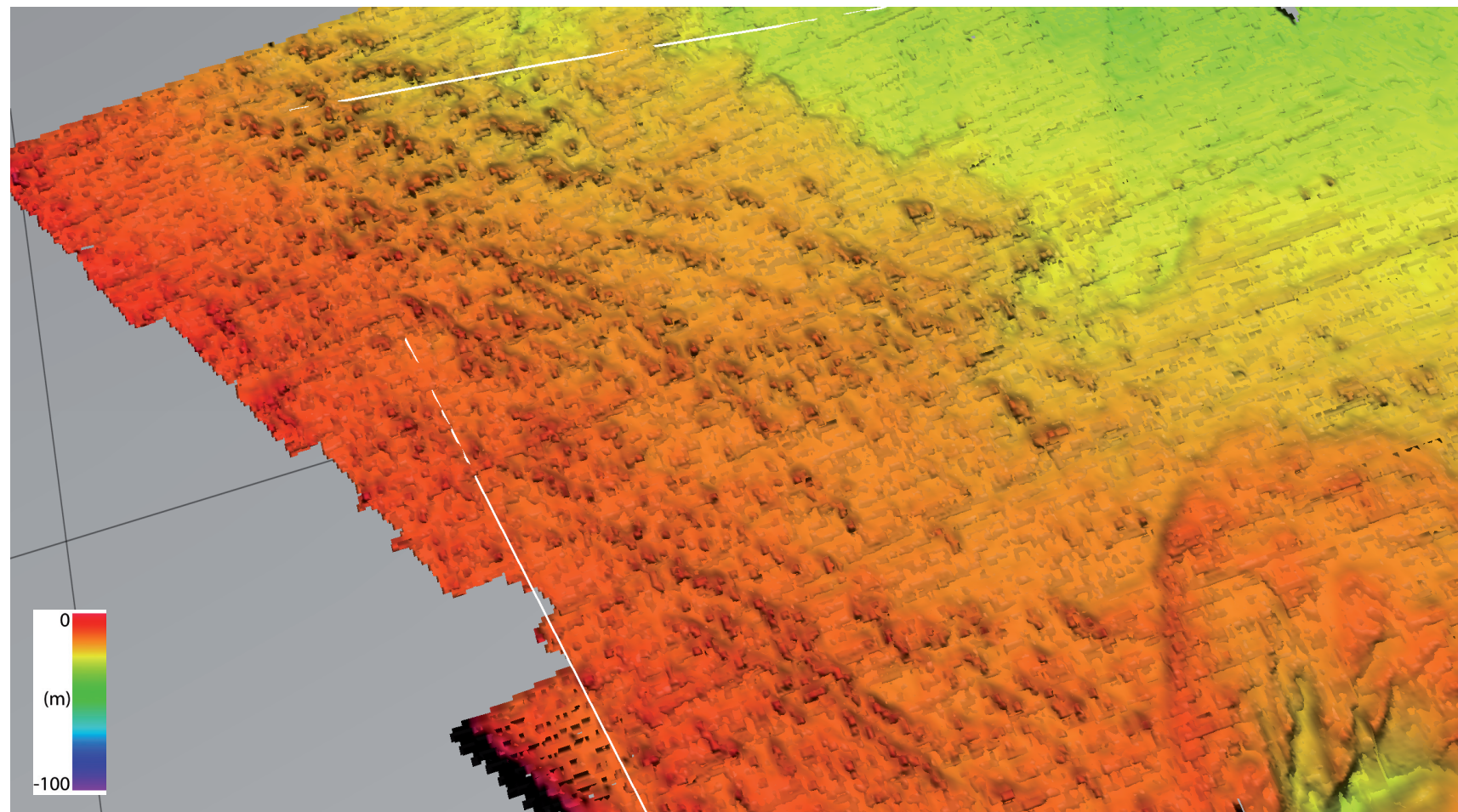


Figure 4.2.30: Obliquely viewed linear sea bed features (aligned from top left to centre) interpreted as submerged shorelines off of Holderness. See Figure 4.2.1 for location. (Single beam echo sounder data © British Crown & SeaZone Solutions Ltd. Licence No. 052008.012. All rights reserved).

(Figure 4.2.6). Sea bed video acquired during the REC survey shows the till to be exposed at seabed or underlying thin coarse-grained sediment cover (Figure 4.2.16).

The SeaZone data, MBES and sidescan sonar indicate large areas of rough and irregular seabed interpreted as thin sediment and eroded till. In the northwest, the SeaZone data shows a series of coast-parallel, linear sea bed features (Figure 4.2.30). These have been interpreted as ancient shorelines (Evans *et al.* 1998). However, the MBES data reveals these features to be of very high relief, thus unlikely to have been formed by changes in sea level. They are more likely to be of direct glacial origin, formed by glaciotectionic deformation or ice melt. In the extreme southwest

of the SeaZone data coverage there are 5 km long NNE–SSW trending low amplitude mounds that are interpreted as moraines (Figure 4.2.31). South of Race Bank and the Outer Dowsing Shoal similar, but more linear, hummocky features are also present.

Sediment Waves

South of Sand Hole there is an area of sandy gravel that forms sediment waves with amplitudes of ~0.5 metres (Figure 4.2.31). The waves are curvilinear, with sinuous and anastomosing crests. They are generally symmetrical, with their crests oriented northwest-southeast. Some steepest slopes face southwest, interpreted as the direction of sediment movement. The SeaZone xyz data is poor to the east of this area of sediment waves, but

it shows that the waves may extend eastward as far as the west bank of the Silver Pit; in which direction they become larger — up to one metre in amplitude (Figure 4.2.31).

The gravelly region in the west is an area where there is the highest current velocity and the greatest tidal range of the Humber REC area (Figures 2.2.1 and 2.2.2.). To transport coarse gravel requires bottom current velocities of 1.5 cm/sec (Stride *et al.* 1982); velocities experienced in the inshore areas off Spurn Head and the Wash (Figure 2.2.1). Thus the transport of coarse-grained gravel in these areas is indeed possible. However, the direction of predicted net sand transport in the area of the gravel waves is southward (Figure 2.4.3), so this does not correlate with orientation of the gravel wave crests, that indicate sediment movement to the southwest. The gravel waves therefore are interpreted as a relict feature.

4.3.2.2 The Intermediate Centre

The region between the Silver and Sole pits is a transitional zone of mainly slightly gravelly sand with a large tongue of sandy gravel protruding from the south. The western Outer Norfolk Banks intrude into this area. North of the Banks there are a number of low amplitude sand banks and large areas of sand waves. The sand waves are up to 5 m in elevation; most are symmetrical, although in the north, the steepest slopes face northward.

4.3.2.3 The Sandy East

In the east of the Humber REC area the sediment distribution trends mainly northwest-southeast. The dominant grain size is slightly gravelly sand and sand with subordinate gravelly sand. Away from the banks and sand wave areas, the sediment cover is thin (Figure 4.2.6). Between Sole Pit and Well Hole (and its southern extensions) the sediment is mainly slightly gravelly sand that forms large areas of sand waves and low amplitude banks. East of Sole Pit the sediment is mainly sandy. In the northeast large sand waves are absent. On north east margin of the REC area is the muddy area of Markham's Hole.

4.3.2.4 Sea Bed Morphology

The large-scale sea bed morphology, the deeps and the banks have already been described above. Here we address the small-scale bedforms, mainly mapped from the REC MBES and sidescan

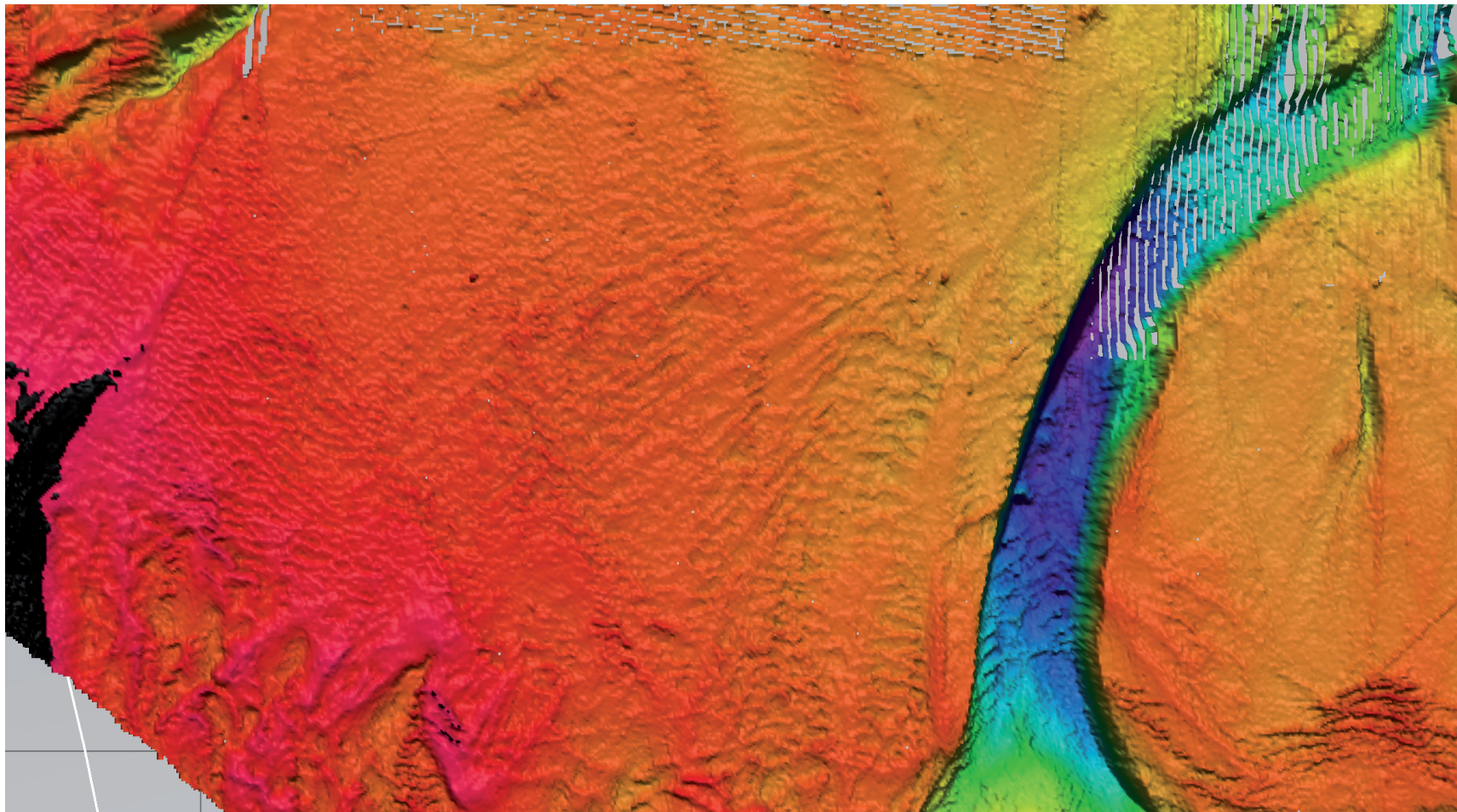


Figure 4.2.31: Low amplitude sediment waves (left) passing to the right (towards Silver Pit) into larger sediment waves. Hummocky features (bottom) interpreted as glacial deposits. See text for discussion. See Figure 4.2.1 for location. (Single beam echo sounder data © British Crown & SeaZone Solutions Ltd. Licence No. 052008.012. All rights reserved).

sonar data; although we also describe the large sand waves as these too are well displayed on this data set.

The general disposition of small-scale bedforms shows some correlation with the sediment distribution, but only in parts. The distribution of large-scale sand waves was mapped from SeaZone data (Figures 4.2.5 and 4.2.6). Sand waves are observed across the whole of the project area, though are particularly common on and around sand banks. The sand wave crests have been mapped and are presented on Figure 4.2.34. As discussed in 4.2.1, sand waves in the REC area display a variation of morphologies which depend primarily on local hydrodynamic conditions. The sediment forming the waves may have a high shell component (Figure

4.2.32) and many overlie a gravel substrate, often with furrows (Figure 4.2.33).

We have performed a semi-automated classification of key sand wave characteristics which include: height, slope, azimuth, and orientation (facing direction), sinuosity, and slope. These metrics were calculated using the gridded MBES data with reference to the sand wave crests which were mapped manually from the MBES data (Figure 4.2.34). The methodology for these calculations is found in Appendix A.

Sand wave amplitudes (height) reach a maximum of 10 m, but have a median value of 3 m (Figure 4.2.35). The avalanche face of the sand waves have a median slope of $\sim 5.9^\circ$ (max= 22°), while

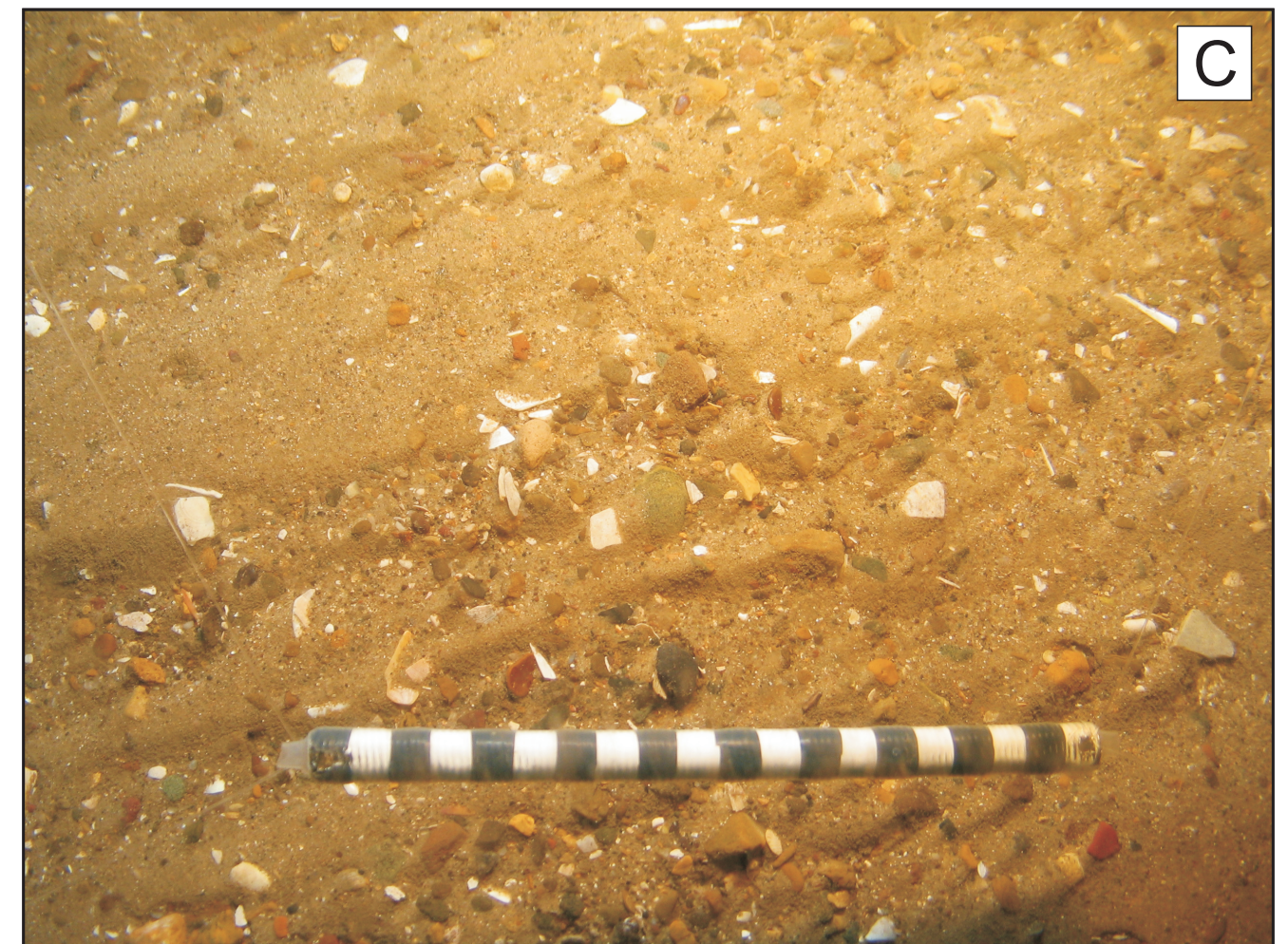
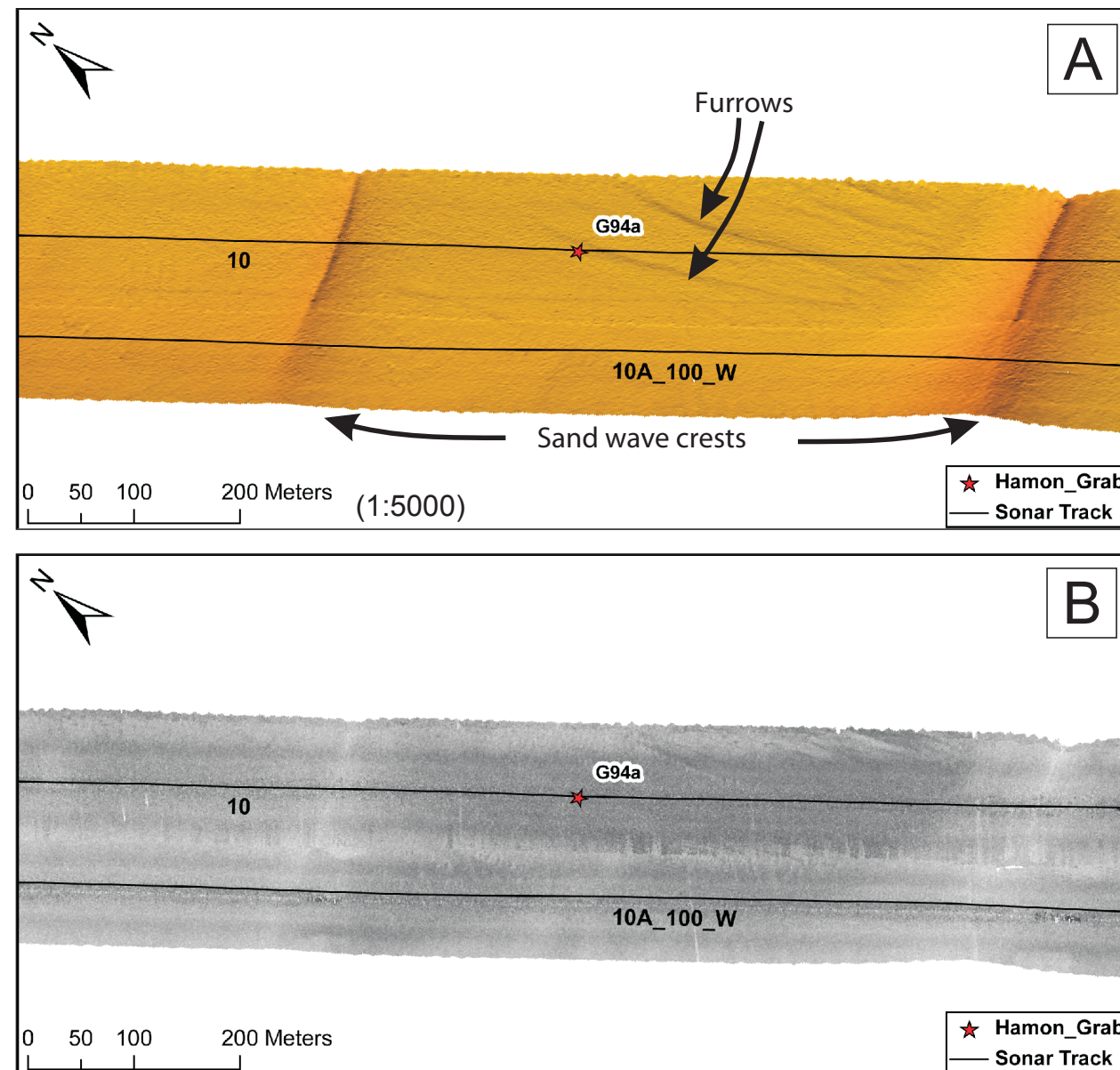
the stoss slopes have a median slope of $\sim 5.8^\circ$ (max= 18°). The similarity in slope between the avalanche and stoss slopes is likely biased by the way in which slope is calculated. The 'slope' value is the mean slope value within a 5 m buffer either side of the crest, thus does not reflect the likely greater difference between maximum slope values of the the avalanche and stoss sides. In other words the slope calculation is accurate for distinguishing which side is steeper, but is conservative in estimating the maximum slope value.

The predominant orientation (facing direction) values of the sand waves are bimodal, trending northnorthwest and southsoutheast (Figure 2.4.36). These orientation values are largely consistent with the predicted sediment transport paths mapped on Figure 2.4.3 (which predict a dominant NNW orientation), however the results presented here show the more southerly (SSE) oriented waves to be more prevalent than expected (Figure 2.4.37). Some of this variation can be explained by the anticlockwise circulation and deposition around the sand banks which is a result of Coriolus forcing, thus resulting in opposing orientations either side of a sand bank. But most of the variation is likely due to a complex system of bottom currents that cannot be imaged at the scale of this study.

The most common small-scale feature mapped is the small sand wave (Figure 4.2.38). These are found everywhere except in the northwest (outside of Sand Hole) and east-centre. They are most common in the central and southeast areas where they are associated with larger sand waves that overlie sandy gravel, so are present where the mobile sediment cover is thin. They are common in the deeps (Figure 4.2.39).

Sand Patches (Figure 4.2.40) and Sand Ribbons (Figure 4.2.41) are found mainly in the north and northeast of the REC areas, although they are concentrated in the northeast. They are mainly found where the sediment cover is thin where they overlie a gravel substrate.

Areas of fluted or grooved seabed (Figure 4.2.42) are found in the north and central regions, but mainly in the north. There is a large area of fluted or grooved seabed south of Sole Pit. The dominant trend of the lineations is northnorthwest-southsoutheast. They again are associated with thin sediment or coarse-grained sediment.



Seabed photograph at G94a

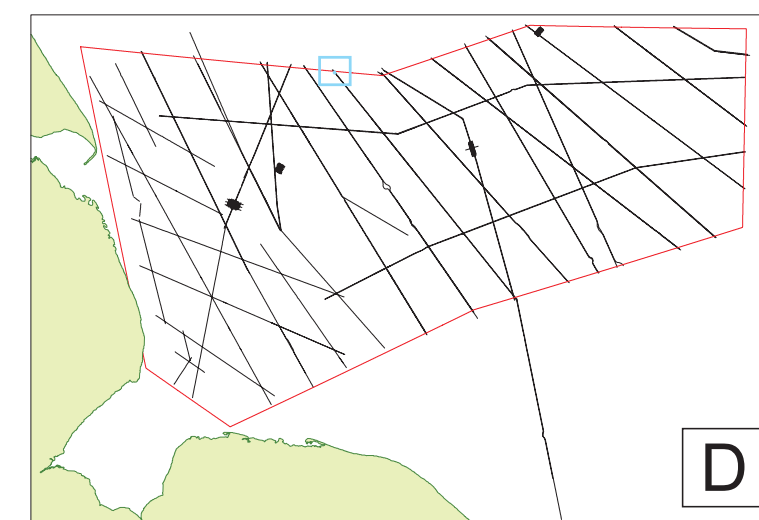
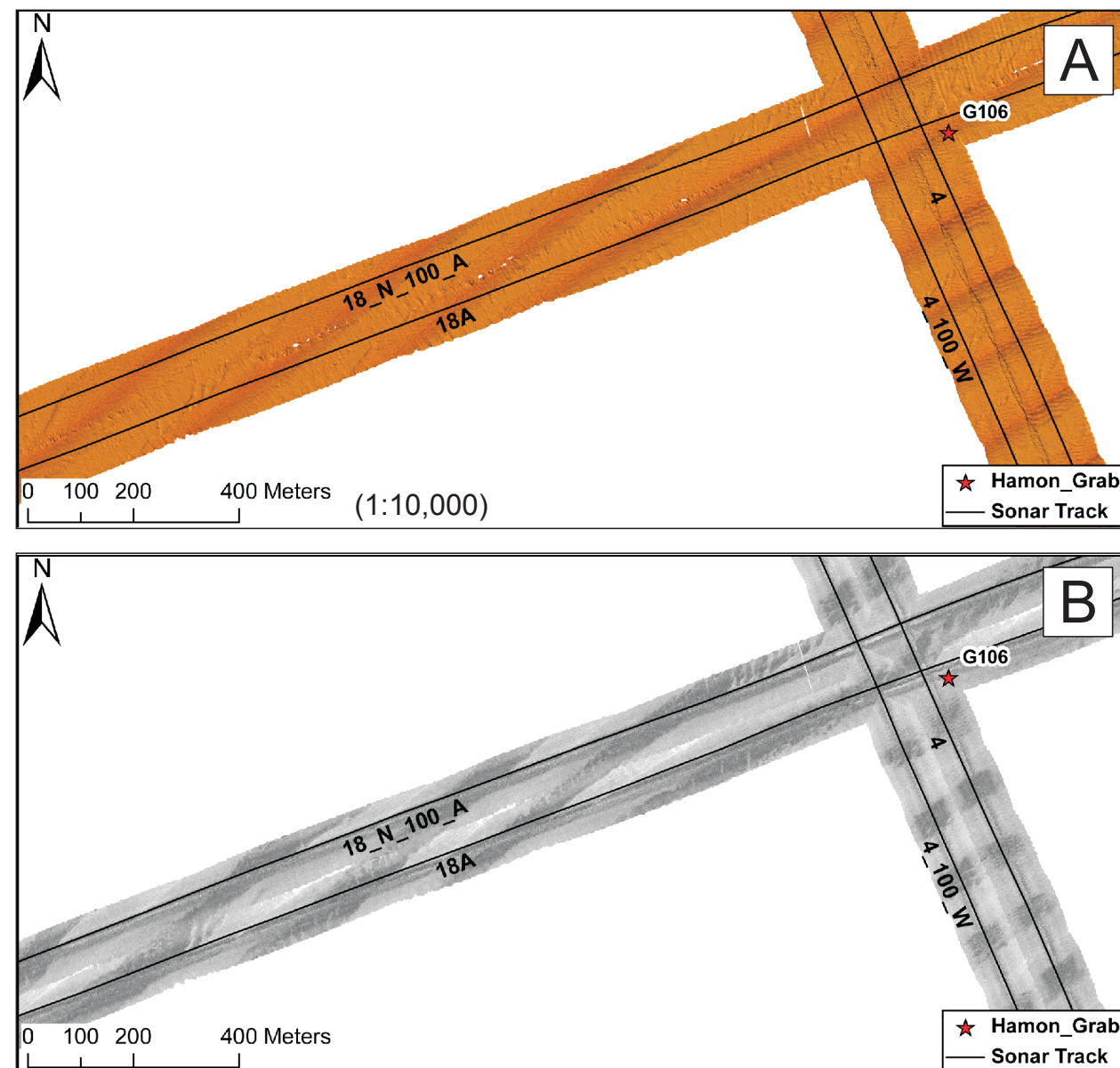


Figure 4.2.32: Common occurrence of mobile sand waves overlying a courser, sandy gravel surface.
A; MBES, B; Sidescan Sonar, C; Seabed photograph shows sandy gravel in trough between sand waves. D; Location map.



Seabed photograph at G106

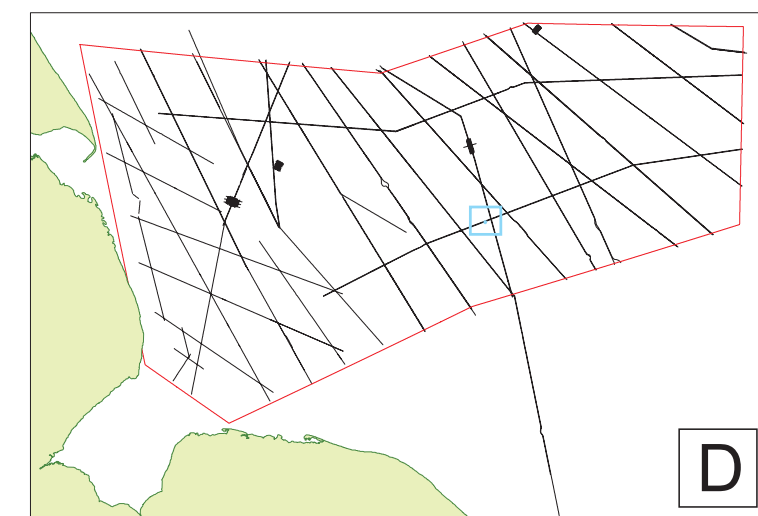
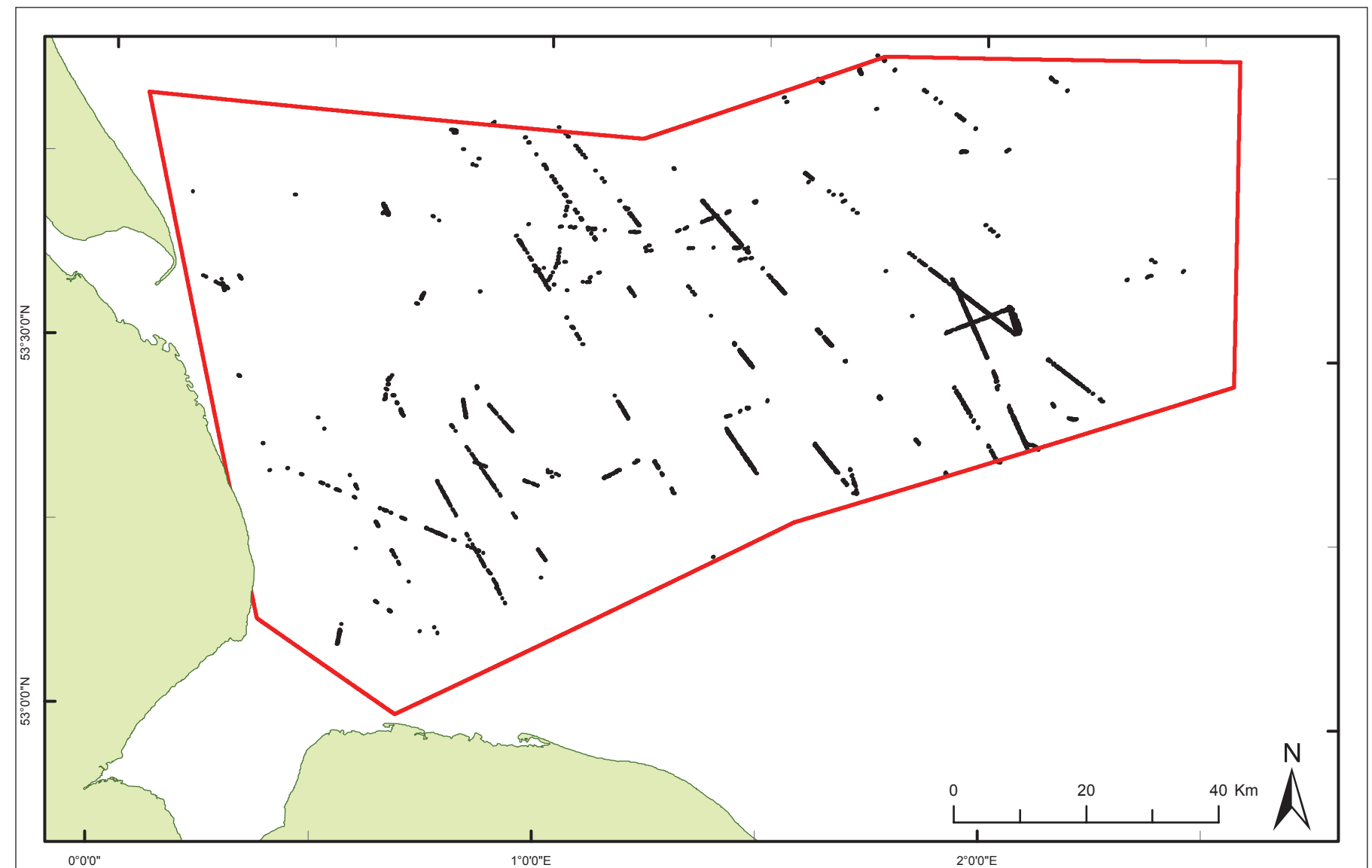
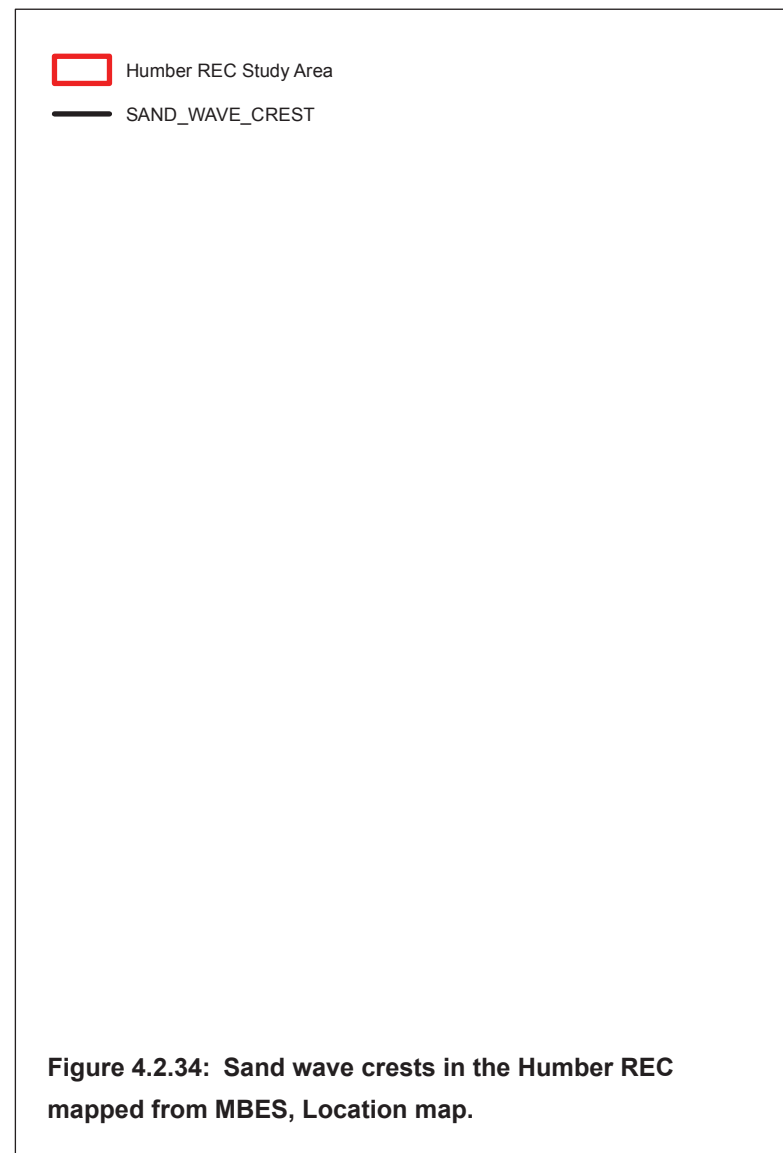


Figure 4.2.33: Large, curvilinear sand waves overlying a coarser surface. A; MBES, B; Sidescan Sonar, C; Seabed photograph shows fine sand at the crest of a sand wave. D; Location map.



Areas of boulders (Figure 4.2.43) are located in the central area between the Sole Pit and Well Hole in areas of gravelly sand.

Areas of high seabed relief and hummocky seabed are located in the Sole and Silver pits and are interpreted as of glacial origin (Figure 4.2.44).

Sea Bed Sediment — Interpretation

Based on the new study of sediment distribution and bedforms in the Humber REC area, a number of new interpretations have been made on the sediment distribution, the bedforms present as well as their origin.

From the new data we find that there is a strong correlation between sandy sediment and the large-scale banks and sand waves. Compared to previous BGS mapping, the banks in the central area are found to be composed of slightly gravelly sand rather than sandy gravel. In the southwest, the sinuous banks are also formed of slightly gravelly sand with sand forming the crestal regions. The sediment forming the sinuous banks has a high proportion of carbonate in the gravel fraction, derived mainly from molluscs. The area of sandy gravel in the west is reduced. There is much less muddy sandy gravel and gravel. The gravel however, is quite muddy (Figure 4.2.15). Outside of major sand banks, the seabed sediment cover is generally thin (cms to dms)

as interpreted from boomer data and BGS legacy shallow cores (Figure 4.2.6). The sediment is thinnest in gravelly areas in the west, outside of the narrow channels incised into the Bolders Bank Formation (Figure 4.2.17).

With regard to the origin of the present sediment distribution and bedforms, we suggest that these features can be accounted for by three main factors;

- The area's location at the Devensian ice margin,
- The post glacial Holocene transgression, and
- The modern hydrodynamic regime

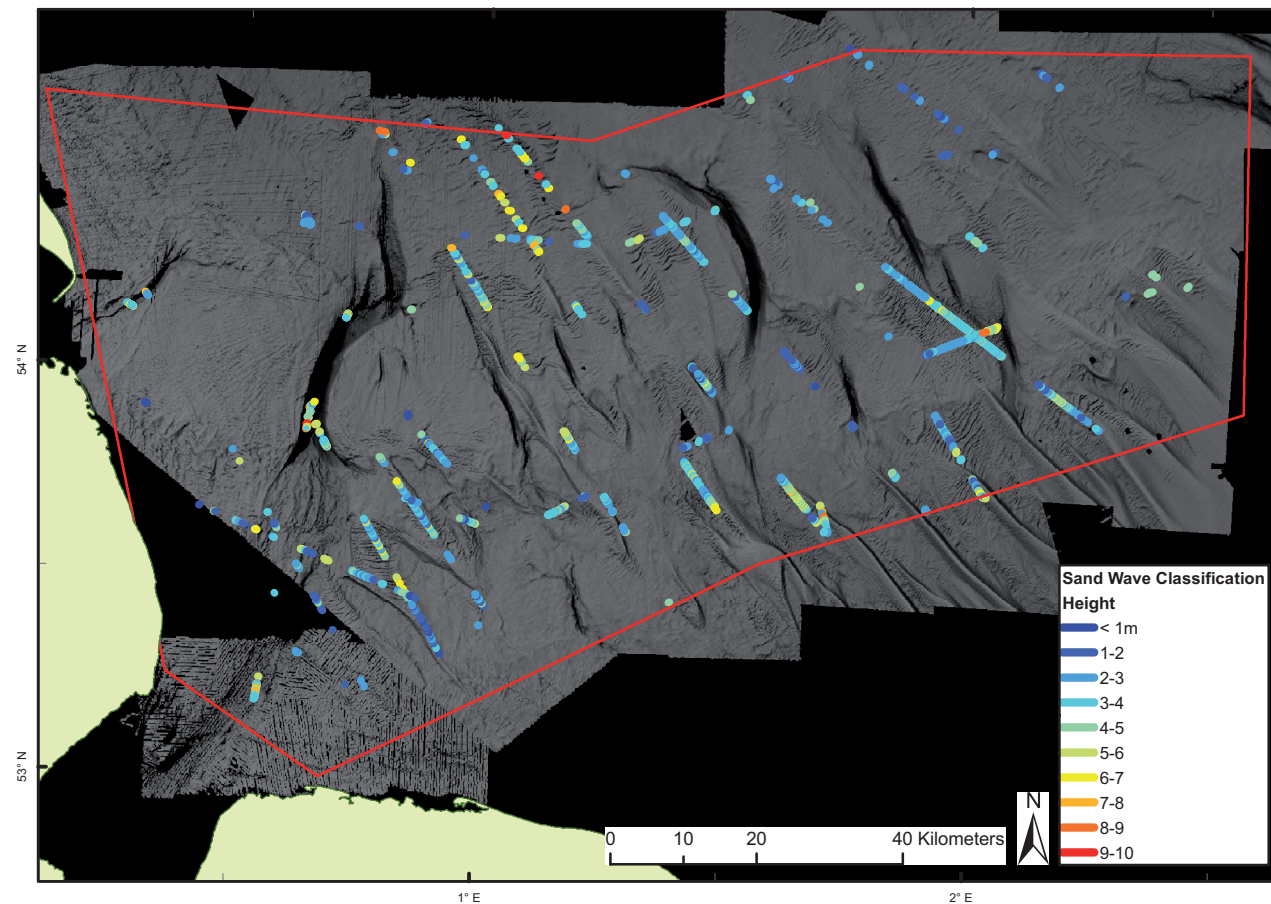


Figure 4.2.35: Map shows the height (amplitude), in metres (m), of the observed sand waves in the Humber REC area; SeaZone bathymetry backdrop.

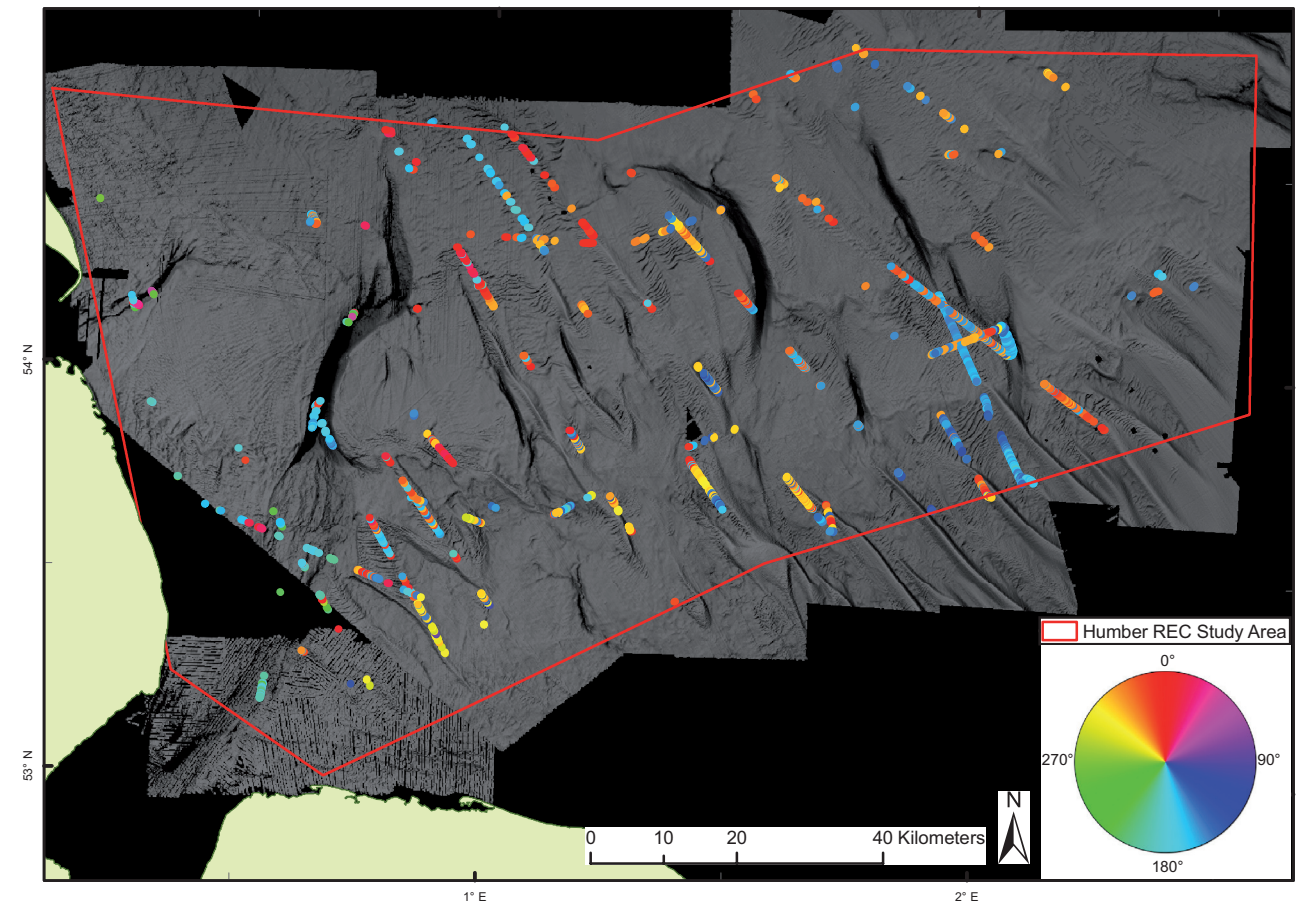


Figure 4.2.37: Map shows facing direction (orientation), in degrees (°), of the observed sand waves; SeaZone bathymetry backdrop.

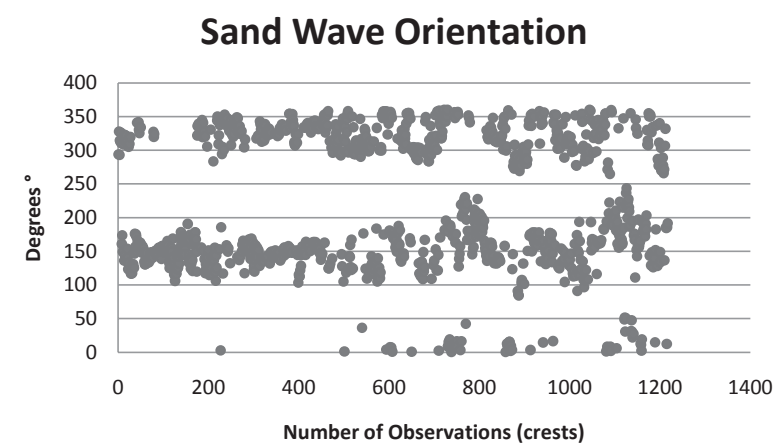


Figure 4.2.36: Chart shows the bimodal distribution (NNW/SSE) in the orientation (Facing Direction) of the observed sand waves.

During the late Devensian the area lay beneath the edge of a continental ice sheet from which was laid down a boulder clay cover up to 30 m thick. Subglacial rivers cut channels in the boulder clay, with some channels filled with coarse-grained sediment. Because the ice margin was located south of the area, most proglacial sediment was shed and deposited farther south on Sandur plains that are commonly found at ice sheet margins.

At the end of the Devensian as the ice sheet retreated, coarse-grained gravel was laid down; derived from erosion of the Bolders Bank Formation. As sea levels rose during the early Holocene, this coarse-grained glacial sediment was winnowed of its fine-grained component, leaving a thin, coarse lag deposit that is now present throughout the region; and at some locations in the west is exposed.

South of the Humber REC area, the thicker, and more extensive, proglacial sediments were reworked into the Outer Norfolk Banks. During transgression some of this fine-grained sediment was transported northward to be formed into the low amplitude banks and large sand waves that are now found in the centre and east of the Humber REC area today. Sediment at this time was plentiful and the zonation of bedforms is that of Belderson *et al.* (1982), in which the sand supply is abundant.

The absence of banks and thicker sand sediment in the northeast is because there were no large banks developed farther southeast that would have acted as a sediment source.

Nearer shore, off Lincolnshire, the strongest sea bed currents winnowed out and removed fine-grained sediment from the glacial lag deposit. Current strength was sufficiently strong to form gravel

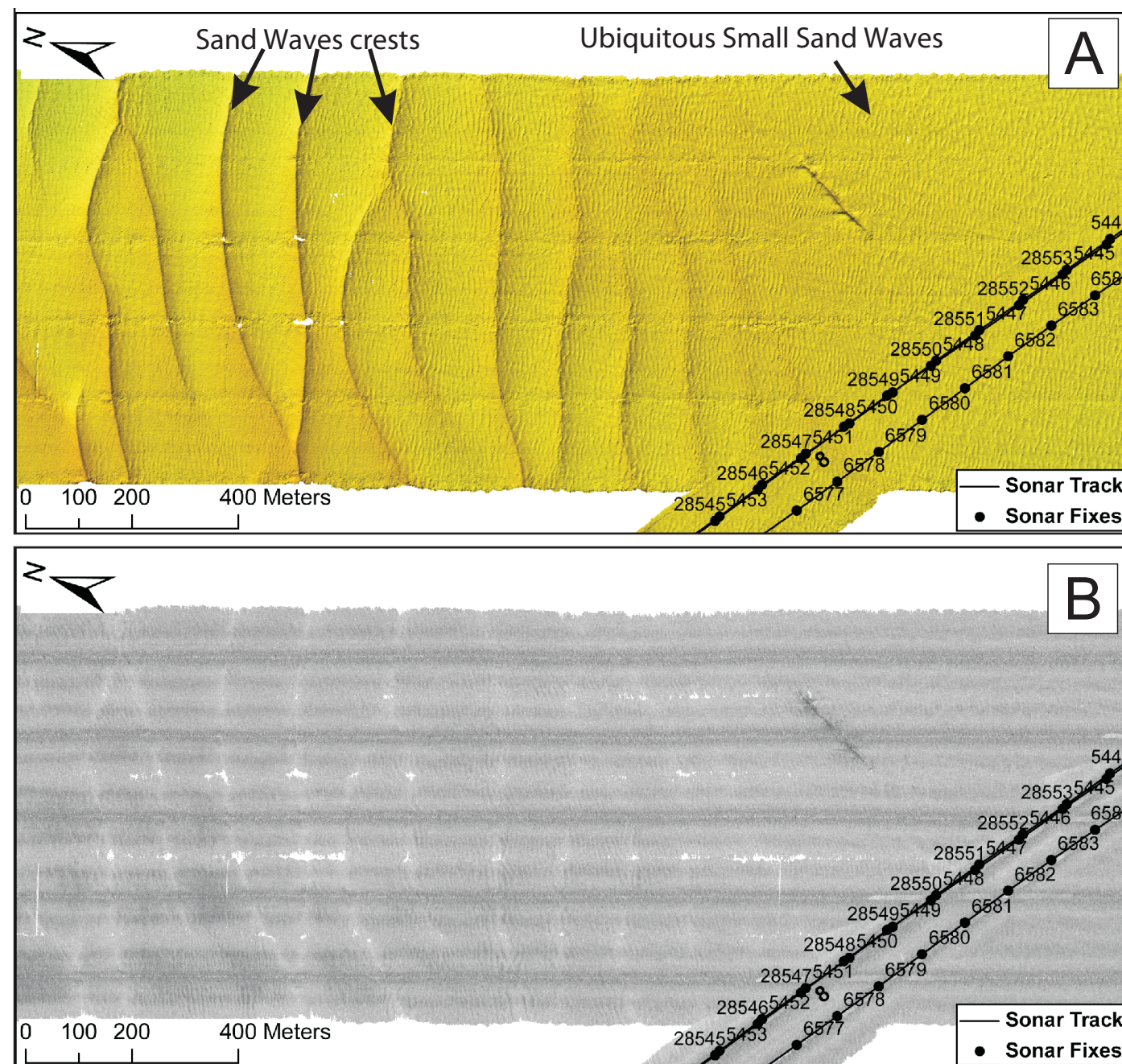


Figure 4.2.38: Ubiquitous small sand waves grading into sand waves in the east of the Humber REC area. The ~200 m linear feature is an exposed pipeline. A; MBES, B; Backscatter, C; Location map.

waves near the coast. Nearshore sediment transport was southerly so much sediment was carried into the Wash, leading to coastal progradation (Brew *et al.* 2000). This sediment may also have been transported into the Race Bank/Dudgeon Shoal area and would have

led to the formation of these sinuous banks. The processes forming the nearshore sinuous banks and outer linear banks in the Humber REC area are considered to be analogous to those forming the Outer Norfolk and the Great Yarmouth banks (Cooper *et al.* 2008).

During the later Holocene, as sea level rise slowed and eventually ceased and the present hydrodynamic regime was established, current strength decreased and the sea bed sediment present was reworked into the smaller sand waves that are so commonly found

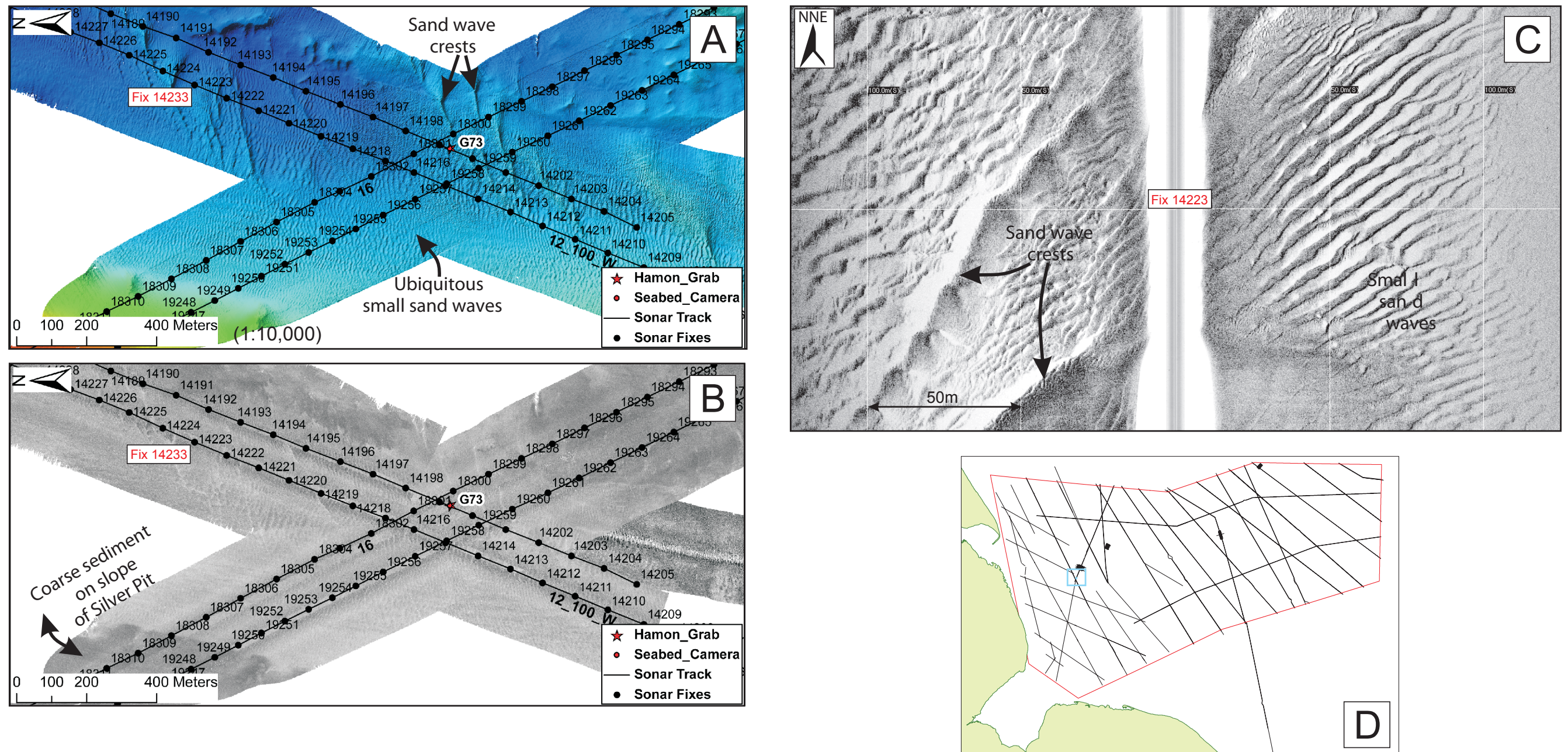


Figure 4.2.39: Small sand waves and several large (Height ~9 m) sand waves (in far NE of A and B) within the Silver Pit. A; MBES, B; Backscatter, C; Sidescan Sonar, D; Location map.

in patches today over most of the Humber REC area. These sand waves were laid down over gravels derived from the degraded glacial till of the Boulders Bank Formation, as well as on the till itself.

Current strengths today are greatest in nearshore areas (Figure 2.2.1), explaining the absence of small sediment waves in this

area. The nearshore area is also distant from sediment sources to the southeast (Norfolk Banks). Perhaps the gravel waves off Lincolnshire do reflect some present day current activity. In the central parts of the Humber REC area the symmetrical morphology of the larger sand waves (except in the vicinity of sand banks) indicates no net sand transport. An interpretation confirmed by

the semiautomated mapping of small sand waves that shows a bimodal distribution of sand wave movement. The lowest currents in the northeast (Figure 2.2.1) explains the absence of small sediment waves in this area.

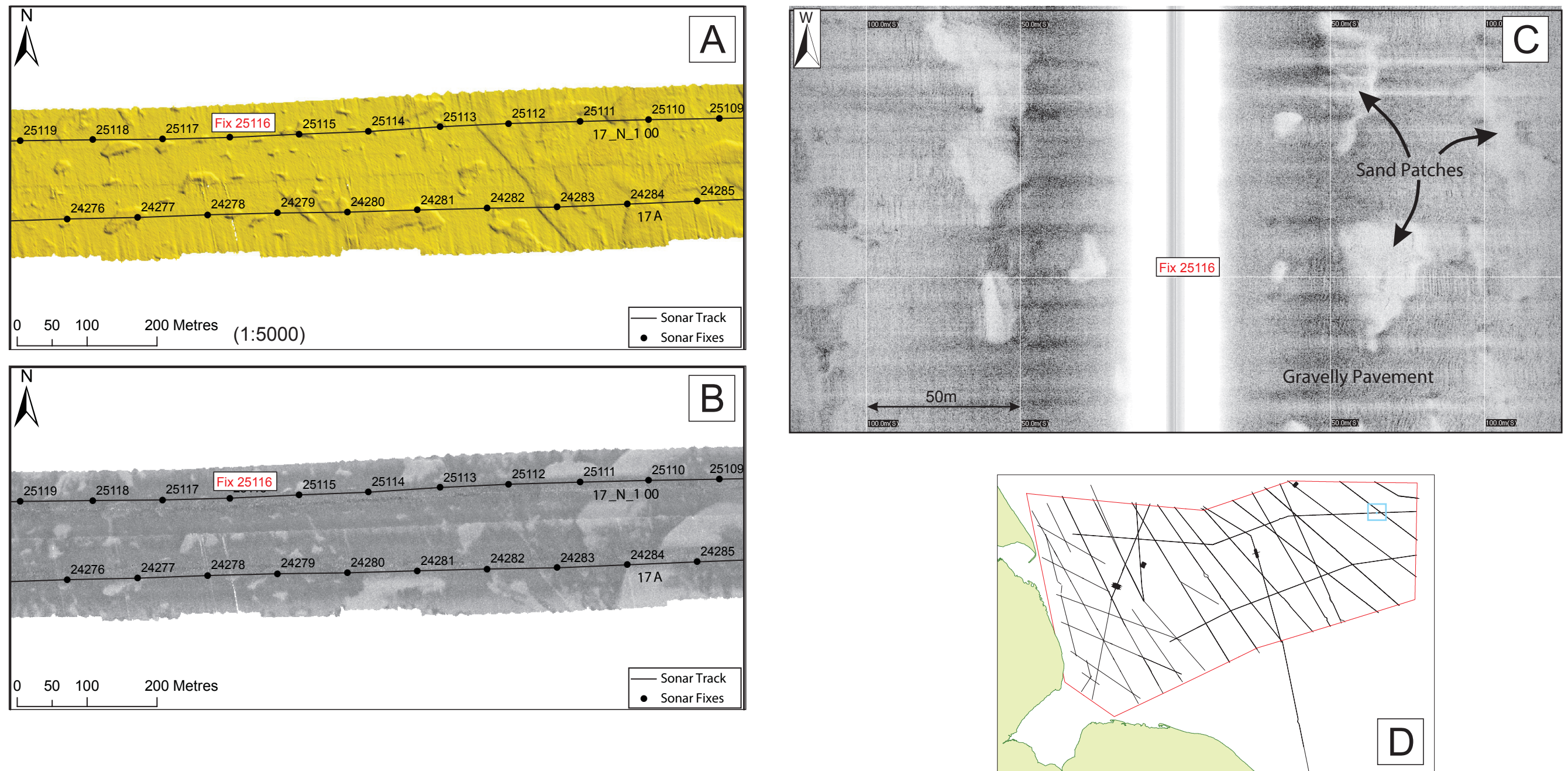


Figure 4.2.40: Sand patches over courser, gravelly pavement in the northeast Humber REC area. A; MBES, B; Backscatter, C; Sidescan Sonar, D; Location map.

4.3.3 Geology Resume

The present seabed morphology and sediment distribution in Humber REC area is attributed mainly to the different processes active in the area over the past 21 000 years, since the Last Glacial Maximum. During maximum glaciation during the Devensian, the area lay at the southern ice sheet margin, and was buried under

an ice cover. During this period the till of Bolders Bank Formation was deposited and sub-glacial fluvial activity cut the channels of the Botney Cut Formation. It is likely that many of the larger deeps now exposed at sea bed were also formed at this time. As the ice retreated the channels were infilled, some perhaps not completely. The landscape would have been similar to the taiga

of northern Canada today, with, moraines and rivers crossing a barren landscape. In low lying areas lakes were formed. While sea level was lowered the major rivers now issuing into the North Sea, such as the Humber, would have flowed out farther across the land surface, perhaps cutting new channels such as the Sand Hole, or conforming to pre-existing topography.

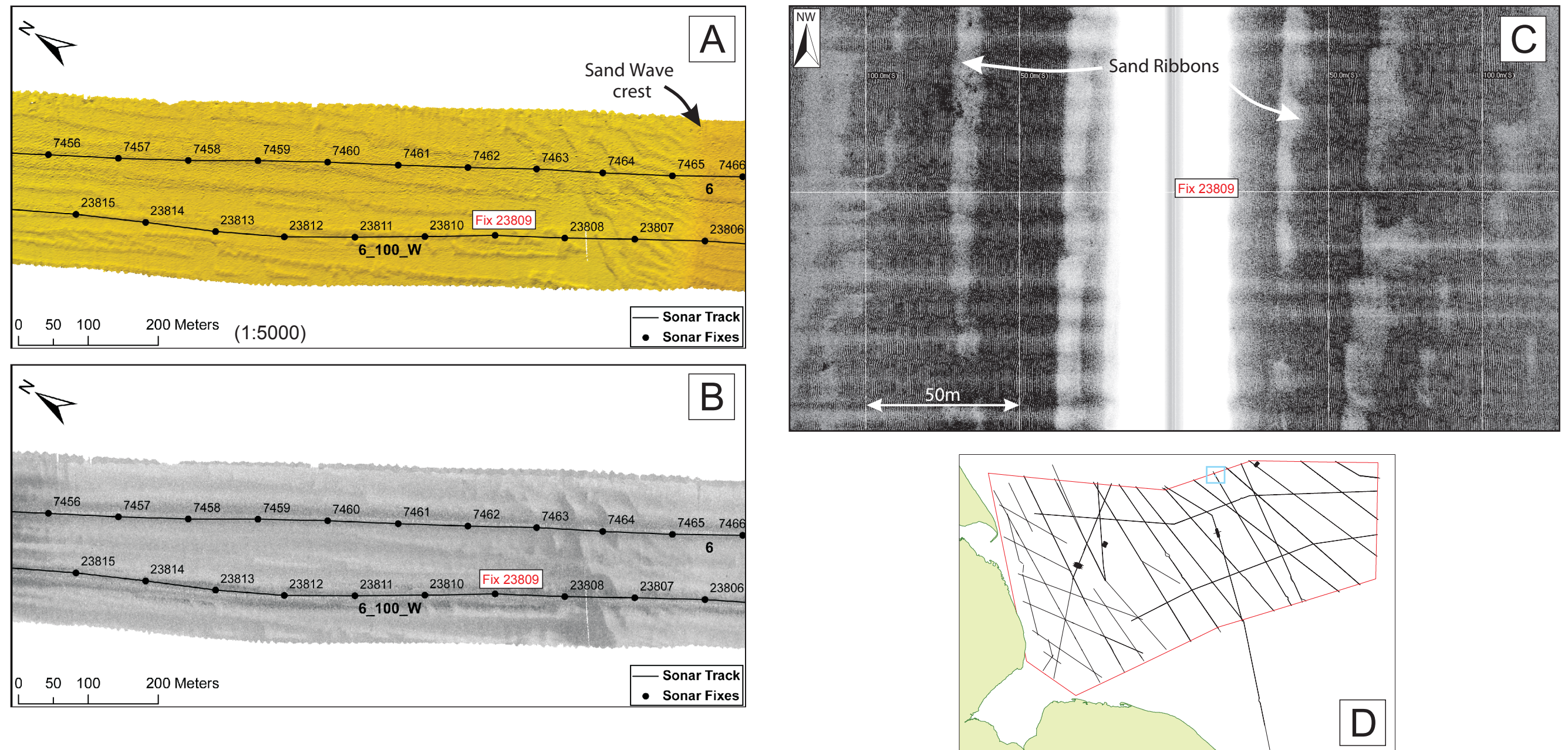


Figure 4.2.41: Sand Ribbons over coarser, gravelly pavement in the north of the Humber REC area. A; MBES, B; Backscatter, C; Sidescan Sonar, D; Location map.

During the mid-Holocene, probably at about 8,000 years BP, as global sea level rose, the area was inundated by the sea. The till of the Bolders Bank Formation was reworked and a relict gravel deposited. This coarse-grained relict sediment was further winnowed of its finer-grained component. At this time, as water depths increased, finer-grained sediment was also transported

into the area from the south. As sea level continued to rise, this sediment was deposited as banks and large sand waves. The rapid passage of the coastal zone across the area resulted in a very energetic regime that led to reworking of the coarse-grained relict glacial sediment present. This energetic regime may have resulted in erosion of sediment from the infilled channels that had formed

subglacially (the Botney Cut Formation). The sediment budget of the Humber REC area was probably smaller than that off East Anglia, because it was overlain by ice, unlike the periglacial, sand-rich environments farther south, thus the sand banks in the Humber REC area are smaller than those off Norfolk. This resulted in a thin sediment cover over the region except in areas of sand banks

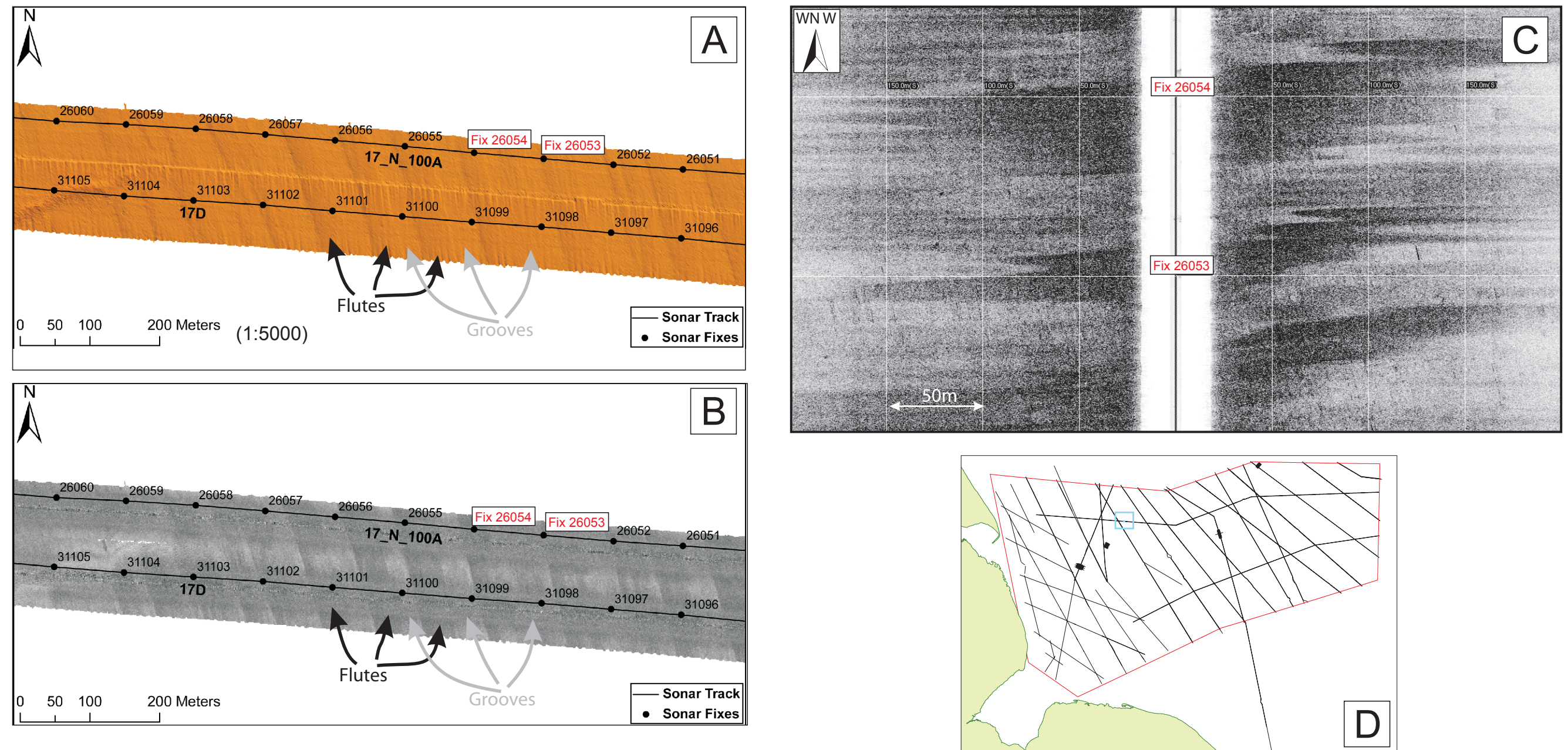


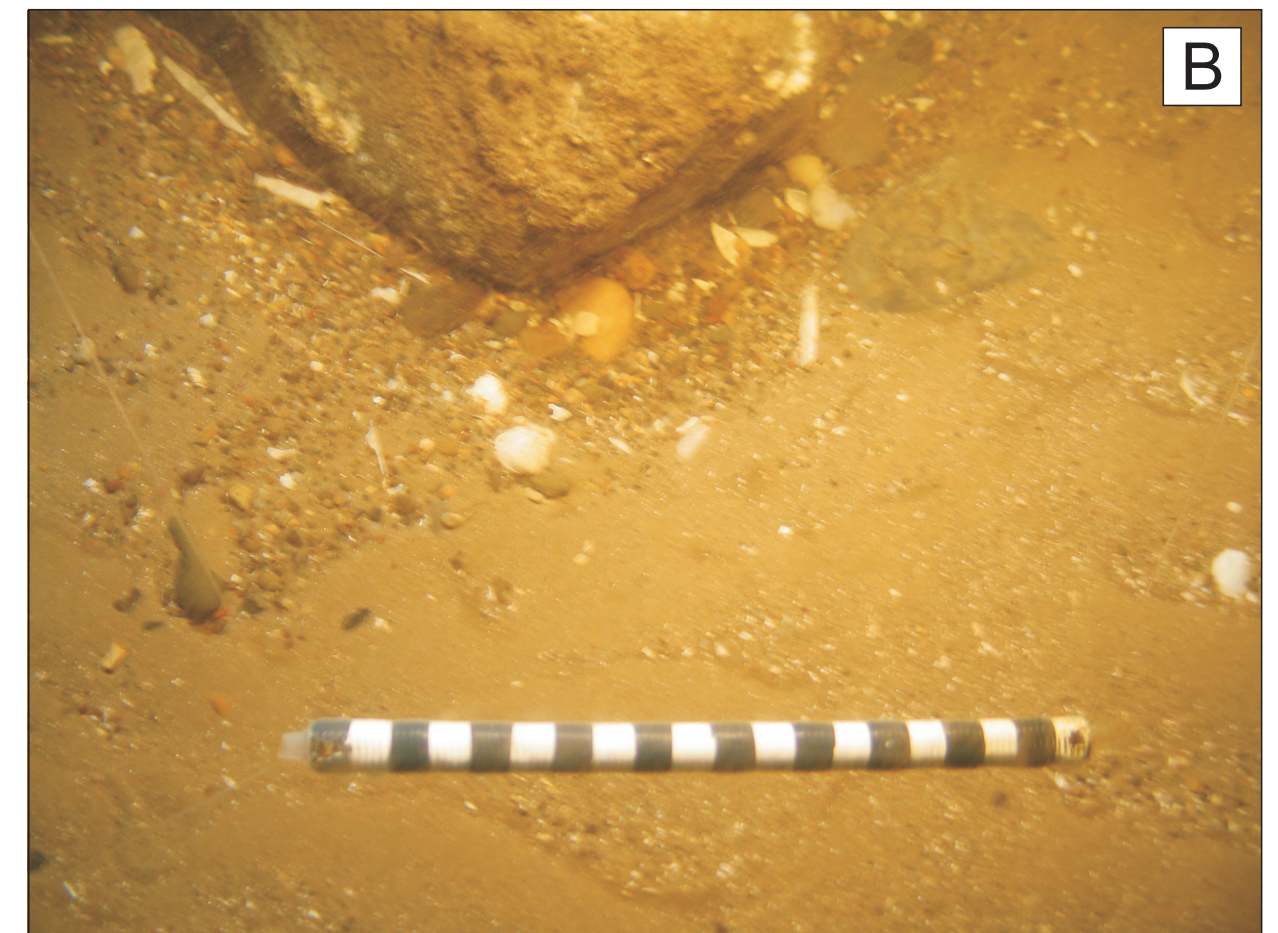
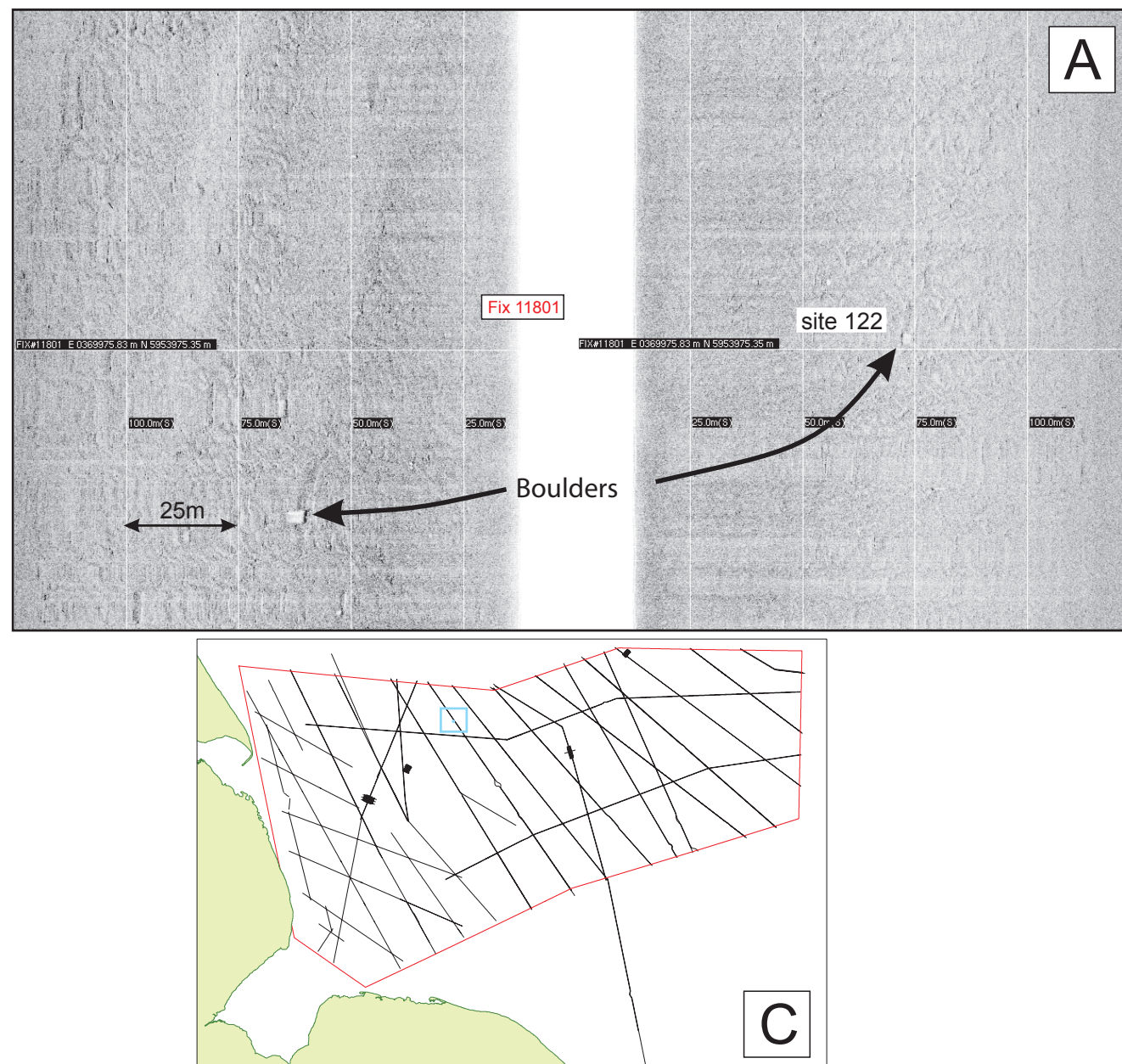
Figure 4.2.42: Areas of fluted (bathymetry high) and grooved (bathymetry low) sea bed in the north of the Humber REC area. In this instance the grooves (lows) are associated with finer sediments resulting from infill. The opposite scenario is also observed where the grooves are associated with coarser sediments where no infill has occurred within the incised surface. A; MBES, B; Backscatter, C; Sidescan Sonar, D; Location map.

and sand waves. The current regime was probably stronger than at present resulting in a regional fining of sediment grain size in a northward direction. Nearer shore, currents were stronger, leading to the area being mainly swept free of fine grained sediment; and strong enough to form gravel waves. Offshore thicker, finer-

grained sediment accumulated; because these areas were directly downstream of the sediment rich areas off Norfolk.

Perhaps it was at this time the furrows and grooves and of the northern and central Humber REC area were formed.

Once sea level had stabilised the sediment at seabed equilibrated with the present hydrodynamic regime. The smaller scale sand waves formed.



Seabed photo at site 122

Figure 4.2.43: Large boulder observed in the north of the Humber REC area. Boulder fields are relatively common in the west of the Humber REC area. A; Sidescan Sonar, B; Sea bed photograph, C; Location map.

5 Archaeology

5.1 Introduction

The archaeological resource of the Humber REC area comprises the prehistoric submerged landscape through to the maritime archaeology of the 20th century. Refining our knowledge of the nature and distribution of archaeological material based on the new data acquired during the REC marine surveys, has enhanced our understanding of the context and spatial distribution of the archaeological resource within the study area and within the wider region as a whole. The research has greatly added to the evidence base for the region, especially with respect to the prehistoric resource. In particular the new evidence obtained shows that the prehistoric landscape extends into the late Upper Palaeolithic and Mesolithic; much earlier in age than previously understood.

A range of heritage data sources was consulted as part of the desk based study in order to identify and assess the marine and maritime archaeological remains known to be present within the study area. These can be grouped into 3 categories — 1) spatial and descriptive data for archaeological sites; 2) background datasets such as topography and geology to put the sites into their environmental context; 3) published documents appraising the general resource, reports concerning other research areas, and documentary sources covering the overall maritime history of the area:

- Historic Environment Records (HERs) and Sites and Monuments Records (SMRs)
- United Kingdom Hydrographic Office (UKHO) wreck information (via SeaZone)
- Private datasets (such as aircraft losses from Ross McNeill)
- Receiver of Wrecks datasets for the region
- Information via websites (such as uboat.net and roll-of-honour.com)
- The Defence of Britain database
- Published DTi and DECC documents
- Birmingham Archaeology datasets (e.g. North Sea Palaeolandscape GIS)
- Published sources

- Archaeology Data Service (ADS) ALSF Archive information
- Historic Sea Charts

The datasets from the Humber REC geophysical survey that were utilised for the evaluation of the archaeology are:-

- Sidescan sonar — high frequency only;
- Magnetometer;
- Sub-bottom profiler;
- Multibeam bathymetry.

5.1.1 Introduction to Geophysical Methods Utilised — Sub-Bottom Profiling

Exploring the submerged prehistoric archaeology of the Humber REC region presents a challenge. As discussed previously these submerged landscapes can be hidden beneath metres of water and marine sediments and may cover hundreds of kilometres in area. Investigating

these landscapes therefore requires technologies that can penetrate the overlying sediments and provide information at a landscape scale. For the Humber REC survey sub-bottom profiling was utilised.

Sub-bottom profilers are seismic-acoustic systems which are able to detect and image structures buried within the sediments. The two systems most commonly used for high-resolution surveying to detect submerged landscapes are the Boomer and Chirp systems. Sub-bottom profilers are generally towed systems that emit an acoustic pulse of energy that penetrates the seafloor and is reflected from sub-bottom changes in acoustic impedance. These changes in acoustic impedance can be caused by sub-surface geology such as different layers within the sediment or the rock, or from buried objects within the sediments. Both techniques are used to measure these differences in a discrete line beneath the acoustic source and thus a vertical profile through the seafloor is derived. The main differences in sub-bottom sonar systems are in the method of producing the acoustic energy. With the Boomer

Sub-bottom Profiling System				
	Wreck Site		Submerged Landscapes	
	Large Area Survey	Detailed Survey	Large Area Survey	Detailed Survey
System type	-	Chirp	Coarse sediments: Boomer Fine sediments: Chirp	Coarse sediments: Boomer Fine sediments: Chirp
Frequency	-	1.5–13 kHz; wide -3 dB bandwidth	Boomer: 200 Hz–15 kHz Chirp: 1.5–13 kHz	Boomer: 200 Hz–15 kHz Chirp: 1.5–13 kHz
Line Spacing	-	5 x 5 m grid/cross the site at least 5 times in areas with strong currents	30 x 30 m	10 x 10 m
Line Direction	-	Perpendicular and parallel to main axis wreck	Perpendicular and parallel to long axis of prominent features	Perpendicular and parallel to long axis of prominent features
Ping rate	-	4–8 Hz	4 Hz	4 Hz
Trace Length	-	50 ms–100 ms	200 ms	200 ms
Navigation	-	DGPS on catamaran/DGPS with USBL	DGPS with layback	DGPS on catamaran / DGPS with USBL
Data Format	-	SEG-Y	SEG-Y	SEG-Y
Survey Speed	-	2.5–3 knots	4 knots	2.5–3 knots

Table 5.1.1: Minimum requirements for archaeological sub-bottom profiling survey from R. Bates 2010.

system the energy is created by a single piezoelectric source that produces an acoustic pulse at approximately 3.5 kHz.

With the Chirp systems, energy is produced over a wider frequency range. The depth of penetration within the sub-bottom for the energy from each system is a function of the frequency and the nature of the sub-bottom material. Table 5.1.1 provides information on the use of sub-bottom profiling in marine archaeological surveys. All modern sub-bottom profiling systems record the acoustic data digitally for later processing and enhancement of the primary signal. The use of sub-bottom profilers has traditionally been to map sub-surface geological horizons for palaeolandscape reconstruction as the chances of surveying over buried objects such as wreck sites is relatively small.

5.1.2 Introduction to Geophysical Methods Utilised — Sidescan Sonar

The sidescan sonar has established itself as the predominant tool for imaging the seafloor because of its good object detection and seafloor character discrimination when deployed with the transducers mounted on a tow fish close to the seafloor. The sidescan sonar is a side-looking sonar with two sets of acoustic transducers aimed at the seafloor to both sides of the tow fish. As the fish is towed across the bottom a ribbon or swath image of the seafloor to either side of the vessel track is generated, in order to produce a near photographic image of the seafloor. Since the sonar ensonifies the seafloor at an angle, the magnitude of return energy is dependent on the shape, size and nature of upstanding features on the seafloor and the roughness of surrounding seafloor. For high-resolution surveying, transducer frequencies typically range between 100 kHz and 900 kHz and modern sidescan sonar systems are capable of resolving objects of 10 cm or less. Typically, the sidescan will ensonify a strip of between 100 m and 600 m wide depending on fish frequency, acoustic power and the height above the seafloor that the fish is towed. When the tow fish is used along a number of parallel lines, if the lines are spaced close together such that there is an overlap between the swaths a map can be produced of the seafloor.

There is an issue with sidescan sonar with respect to the absolute error in the position of the object on the seafloor due to the fact that the position and orientation of the sonar fish in the water column behind the boat is often poorly known. The absolute error in position can be

improved with these systems through the use of ground control points either from known, precisely located, objects on the seafloor or through the use of an acoustic beacon deployed on the towed instrument.

5.1.3 Introduction to Geophysical Methods Utilised — Multibeam

Multibeam sonar uses a combination of hardware and software control of multiple transducers to produce a number of sonar signals or beams that propagate from the sonar head in a fan and return a bathymetric and amplitude measure of the seafloor along the swath covered by the boat track. The method produces a bathymetric map of the seafloor, which can be mosaiced into a full 3D chart if there is sufficient overlap between each swath. Most multibeam systems are hull mounted, and with high-resolution systems using frequencies of up to 450 kHz, objects of 20 cm may be discriminated. Because the multibeam is hull mounted the beam angles result in amplitude maps that lack the dynamic range of the true sidescan images. However, the amplitude maps have the advantage that the amplitudes are co-located with the bathymetry in true geographic space. For archaeological investigations, very detailed models can be produced of upstanding wrecks on the seafloor using the multibeam sonar when it is deployed close to the object that is to be investigated. However, this requires dedicated time to survey at pre-determined locations and is not conducive to routine line surveying. In addition to producing high resolution models of upstanding archaeological features, the method has also successfully been applied to mapping palaeolandscapes where they are coincident with the modern seafloor.

5.1.4 Introduction to Geophysical Methods Utilised — Marine Magnetometry

Marine Magnetometers are tuned to measure small variations in the Earth's magnetic field due to local geological features and disturbances caused by ferromagnetic anthropogenic objects. The magnetometers are towed at sufficient distance behind the survey vessel so that they do not record the signature of the vessel itself. It is also desirable that they are towed as close to the seafloor as possible in order to best record the response of the seafloor and features on it as opposed to measuring the regional geological signature.

5.1.5 Sub-Bottom Profiling — Methodology and Assessment

The shallow seismic geophysical dataset provided from the Humber REC survey consisted of 2D Boomer lines collected by Gardline Surveys Limited. Traditional seismic reflection data is usually referred to as 2D because the data is collected via a single cable or streamer, and as the shallow seismic survey penetrates the seabed, the information displayed is effectively a vertical slice through the sediment column. Consequently, specific features, such as river channels, may be located with a vertical profile, and shallow 2D seismic surveys therefore aid the detection of palaeogeographic features which may possess archaeological potential.

The shallow seismic geophysical dataset was acquired between October 2008 and March 2009 as two separate surveys; an offshore survey in waters deeper than 30 m and later a nearshore survey in shallower waters. Together both surveys covered extensive sections of the Study Area and are consistent with the objectives of producing a regional characterisation. This data was obtained by the Gardline Vessel Vigilant, which was equipped with a surface-towed boomer consisting of an Applied Acoustics 300 Plate with an Applied Acoustics CSP 1500 Bang Box. The multi-element single channel hydrophone, a Gardline 2012, was equipped with both analogue and digital data recording capabilities. Data logging and initial processing was accomplished with an Octopus 760, and a swell filter was applied to the data when required. The system was generally operated at a power level of 300 joules at a 350-millisecond fire rate which is comparable to similar surveys (eg. Wessex Archaeology 2009).

The instrument was used on all profiles, and produced moderate or good data. Useful data was generally recovered to a depth in excess of 25 metres below seabed, and the depth of useful recovered data is thought to be a function of the nature of the shallow geology rather than tuning.

The sub-bottom-data was digitally recorded and stored and provided to Birmingham University in standard SEG-Y format. Corresponding survey track information was provisioned directly from the SEG-Y which contain the necessary spatial information. This data was initially inspected and processing accomplished using both SonarMap (Chesapeake Ltd) and GeoSurvey 3.11.3 (Coda Ltd) and at Birmingham was further

processed using SMT Kingdom 8.4 (64 bit) and visualised utilising MCS Avizo Earth Edition 6.2. A number of post acquisition processing steps were applied to the data which included bandpass filtering, time varied gain and running-sum amplitude gain correction. Sub-surface layers were picked where evident above background noise. The data was inspected in detail where anomalies had been noted in the sidescan and multibeam sonar surveys, in order to determine the depth extent of the anomalies.

It was observed that there was some variation in quality of the seismic datasets received. From the available information it is apparent that this results from the weather conditions in which the survey was undertaken. Indeed weather conditions in some lines affected the survey data to sufficient degree that they were effectively unusable for archaeological purposes. These affected lines were resurveyed during the 2nd stage of the main survey.

The lines resulting from the survey were of an adequate quality for archaeological interpretation in spite of the problems observed above during their acquisition. Datasets acquired during good weather were characterised by strong clear seismic returns. Those from the poorer weather sections of the survey contained noise and discontinuous reflectors (see Figure 5.1.1). This impeded the interpretation and mapping of smaller palaeogeographical features in these lines. Minor periodic noise originating from the vessel is also apparent in some of the survey lines (see Figure 5.1.2). Additionally

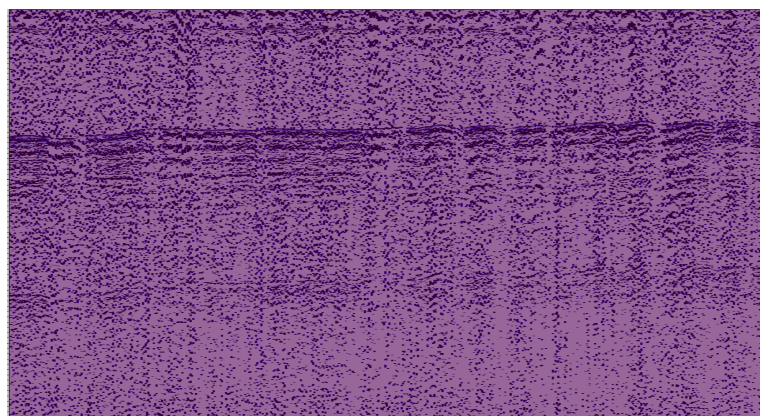


Figure 5.1.1: Illustration of noise due to poor weather conditions. In this example the noise disrupts the reflector continuity and reduces the maximum observable depth.

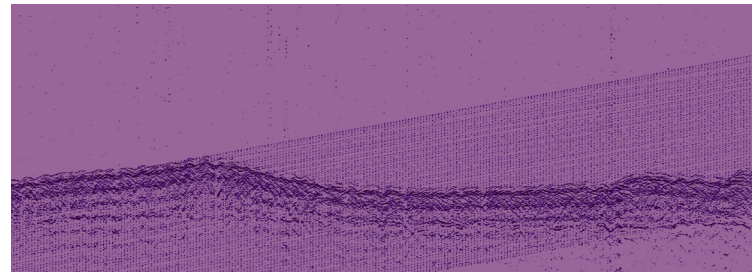


Figure 5.1.2: Illustration of the periodic noise within the dataset, in this example derived from equipment onboard the survey vessel itself. Whilst this noise is problematic, it does not greatly affect the dataset.

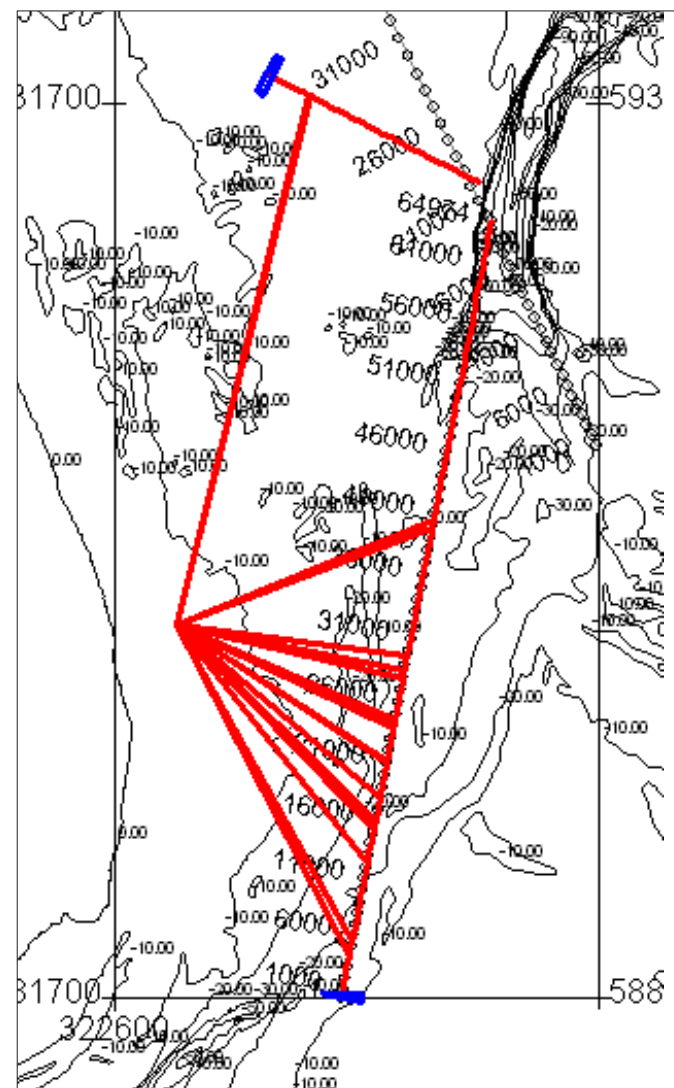


Figure 5.1.3: Illustration of Navigational Dropouts located within the Nearshore Surveys.

periodic navigation dropouts were also observed within the SEG-Y lines provided for the nearshore survey (see Figure 5.1.3), however these dropouts did not seriously affect the overall data quality.

Within the geophysical data two main types of features of archaeological interest were observed. These are:-

- Erosion Surfaces (palaeoland surfaces) Figure 5.1.4
- Cuts and Fills (palaeochannels) Figure 5.1.5

Of these features, the cut and fill type occurs most frequently. These features are generally associated with fluvial action within the study area. As it is advantageous to live in proximity to fluvial features, and as these have also been argued to be used as routeways by Mesolithic people, (Bell 2007, Waddington 2007 and Schulting and Richards 2000) they are significant in the archaeological landscape. Additionally, material may also be preferentially preserved in palaeochannels as their incised nature protects deposits containing artefacts.

Several strong negative phase signals were observed within the palaeochannels. These have been hypothesised as being associated with the boundaries of peat deposits (Plets 2007). Peat layers are indicative of sub-aerial exposure and have a high potential for preservation of archaeo-environmental material. Subsequent coring of these sites revealed the presence of peat layers at these locations, thus it is likely that similar such signals within this region may well be associated with this type of deposit and can be utilised as indicators of archaeo-environmental potential.

The other main type of features observed are erosional surfaces. These surfaces are represented within the geophysical data set by a series of shallow undulating cut surfaces that are associated with past land surfaces buried by later sedimentation. Since these cuts represent past landscape surfaces, they have the potential to contain archaeological material within primary contexts.

More detailed study of the nature of 'cut and fill' features was undertaken in the two areas of detailed archaeological survey and the results are provided in Section 5.4.2. This was achieved through the utilisation of much closer geophysical line spacing than utilised in the main geophysical survey. In addition the results were



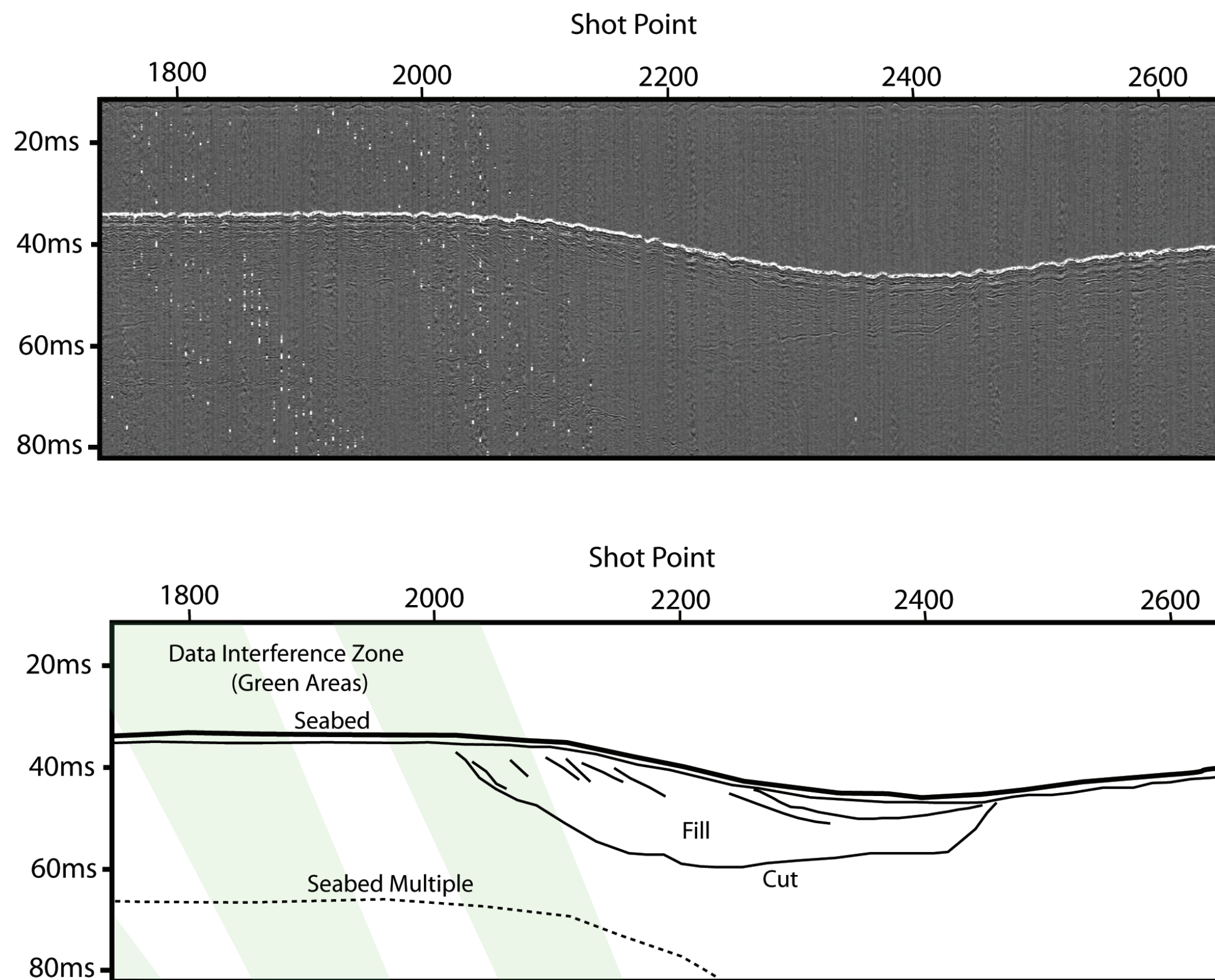


Figure 5.1.5: Cut and Fill feature located in line 'Arch 2_10'.

validated by targeted palaeoenvironmental coring. For the majority of the study area however it was not possible to achieve this level of study, so evidence from the widely spaced regional lines was supplemented by existing BGS legacy datasets and the results of Birmingham Universities NSPP survey (Gaffney *et al.* 2007). Correspondence between these pre-existing datasets and the REC regional survey lines was good and facilitated the characterisation of the palaeolandscape across the region.

5.1.6 Sidescan Sonar and Multibeam Sonar — Methodology and Assessment

For this survey an Edgetech 420F sidescan sonar was operated with both 100 and 420 kHz transducers. The survey fish was deployed with an acoustic beacon in order to better locate its absolute position. Sidescan sonar data was recorded in standard XTF digital format.

This allowed the data to be reviewed with a number of geophysical survey software packages. For this project SonarMap (Chesapeake Ltd) and GeoSurvey 3.11.3 (Coda Ltd) were used for individual line inspection. Both of these programmes allowed post-acquisition processing including amplitude enhancement using time varied gains, beam angle corrections and customised gain functions. In addition, post processing allowed correct geo-referencing of the sidescan data in order that individual targets could be geographically located and thus a comparison made between sidescan signatures and those derived from the multibeam sonar. Each sidescan file was analysed for upstanding features and changes in surface texture that could be associated with either specific archaeological targets or broad archaeological landscape features.

The multibeam sonar data was recorded and processed using a combination of industry standard protocols. Processing included filtering for weak signal, data points out with the beam angles, non-coherent bottom returns and correction for speed of sound. The final output of the multibeam was a swath of information in the form of a bathymetric terrain model registered in true world coordinate UTM 31N x,y,z, data points. Processing of the multibeam data was undertaken by the survey contractor using proprietary software (Caris HIPS and SIPS v 6.1) in association with the multibeam acquisition system. Output from the processing also included geotiffs of the seabed relief at 1 m and 2 m bin resolution. These files were useful for a quick visual check of each line before further viewing

and analysis using the IVS Fledermaus software programme. This programme allowed each swath line to be inspected for targets and anomalous seafloor together with the more detailed inspection of signatures associated with known wreck sites.

5.1.7 Magnetometry — Methodology and Assessment

For this survey a Geometrics G882 magnetometer was used. This was towed 100 m behind the vessel and operated at a rate of 1 Hz. The magnetometer is sensitive to 0.02 nT. It was operated with a dedicated sonar beacon and therefore the absolute position of the instrument was only based on an extrapolation of the boat's position and the assumption that the instrument was lying directly astern of the survey vessel. Output from the magnetometer (total magnetic field strength and instrument position) is provided in ascii format.

The marine magnetic data did not require any further processing after acquisition and export. The final data was plotted as line track information in ArcGIS and examined in relation to the sonar data. Coincidences of Magnetometer change with the sidescan data were sought, as these could reveal additional sites of archaeological potential. However no convincing correlations were observed.

5.2 Submerged Prehistoric Landscapes and their Archaeology — A Brief Introduction

The marine area of the Humber REC area contains a record of prehistoric landscapes from a variety of periods between 700 000BP and 5 000BP which were once an extension of the terrestrial landscape. Whilst the study area is currently a marine zone, it is important to remember that it would have constituted dry land for considerable periods of time, when it would have been occupied by hominins. Therefore the deposits relating to these landscapes not only have the potential to contain archaeological material, but also to have archaeo-environmental significance through the preservation of landscape and environmental data.

The presence of earlier landscapes (700 000BP to 18 000BP) is problematic within the Humber REC region as these have been modified by repeated marine transgressions, glaciations and sub-aerial erosion. The presence of early hominins in Britain during this period, indicates that there is a potential for Palaeolithic artefacts within

this region (see table 5.2.1). These are most likely to be derived from secondary contexts due to the high level of erosion and reworking in this area, related to the actions of ice, marine and fluvial processes, however, some *in situ* deposits are present (see Table 5.2.1).

As such, in the Humber REC area the most likely form of archaeological potential relates to the submerged landscape of the Late Palaeolithic to Mesolithic (18 000 to 6 000BP — see table 5.2.1) which developed after the last glacial maximum (18 000 BP). The landscape of this period is much better understood than earlier periods through the work of the ALSF Funded North Sea Palaeolandscape Project (NSPP).

5.2.1 Lower to Early Upper Palaeolithic — Sea Level Change and Glaciation

The Humber REC area has potential for early prehistoric archaeology the distribution of which is closely related to changes in relative sea level and glacial conditions in the region. Since the first archaeologically recorded hominid occupation of Britain *circa* 700 000 BP the North Sea basin has been sub aerially exposed on repeated occasions (see Figure 5.2.1) due to changes in sea level related to the growth and degradation of polar ice sheets. Although Figure 5.2.1 only extends back to 140 000 BP, relative sea level changes occurred throughout the period of hominid occupation of this region. Modern Human occupation of these landscapes is evidenced in Britain at around 40 000BP (Gamble 1996). The sub aerial exposure of what is presently the seabed of the North Sea would have presented a viable landscape for occupation.

Sea level change clearly had a controlling influence on the terrestrial linkages of Britain in relation to Europe during these early periods of prehistory, with rising sea levels leading to the 'inundation' of the land bridge (Preece 1995). Although the exact nature of these breaches is not fully known, the present understanding of the periods of breaching of the land bridge is illustrated in Figure 5.2.2. It is apparent that there are several relevant periods when Britain formed an island (Gibbard 2007). Perhaps the most significant of these breaches occurred during the Ipswichian interglacial (5e). Human movements into Britain may have been halted at this time, as shown by the present terrestrial archaeological record which indicates that Britain was not inhabited during the period 180 000 to 60 000 BP (Stringer 2006: 156).

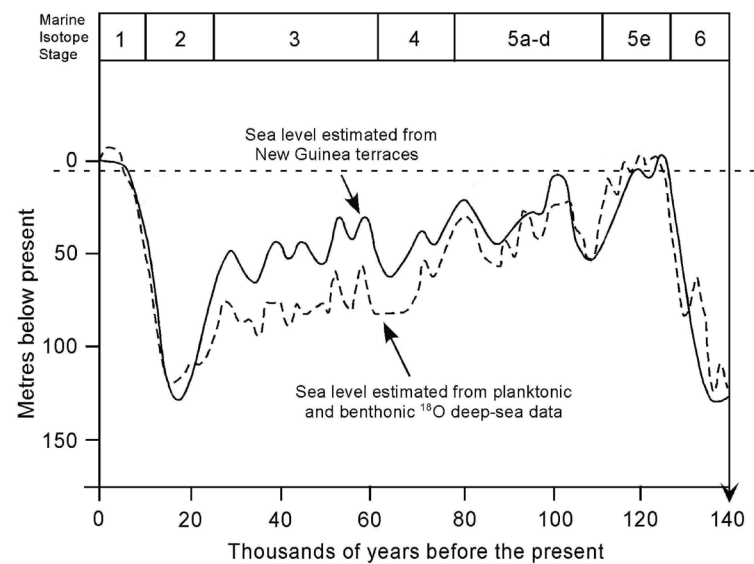


Figure 5.2.1: Relative sea level during the past 140 000 years.

The survival of deposits of archaeological potential of the North Sea basin has been affected by several glaciations. These periods of extensive ice coverage would have prevented or severely impeded access to the region to human populations (see Figure 5.2.2). For example, during the Anglian glacial phase (*circa* 478 000 to 424 000 BP) ice sheets would have extended nearly to the Thames, whilst the areas of Britain immediately south of the ice would have been a polar desert (Stringer 2006: 88).

The presence of a Wolstonian glaciation remains contentious; indeed as displayed in Figure 5.2.2 it's existence as an individual event is debatable, as there are 'cold' stages within the time period given for the Wolstonian (380 000 to 130 000BP). Therefore the ice sheet models displayed by Gibbard (1988) and Woodcock (2000) still have relevance. These models suggest that the limit of the ice advances within the period of time occupied by the Wolstonian are roughly comparable to those of the furthest limits of the Devensian and thus would have covered most of the study area.

During the Devensian glaciation (*circa* 73 000 BP to 10 000 BP) the ice sheet covered most of the study area. Some uncertainty exists to the limit of the ice cover (approximately 18 000 BP) over the area during the last glacial maximum (LGM), with Boulton *et al.* (1991) suggesting extensive coverage of the study area, whilst

Prehistoric Archaeology Summary Table					
Geological Period	Archaeology Period	Date	Deposits	Potential in Region	Exposure in Study Area
Mid to Late Holocene	Submerged — Maritime potential only	6 000 BP to Present Day	Nieuw Zealand Gronden Formation, Well Hole Formation, Modern Sediments	Derived Artefacts only	Almost all of the Study Area
Early Holocene	Late Upper Palaeolithic/ Mesolithic	13 000 BP to 6 000 BP	Elbow Formation	Derived and <i>In situ</i> Potential	East and South of Study Area — Probably Absent in Extreme West of Study Area
Earliest Holocene/ Late Pleistocene	Late Upper Palaeolithic	20 000 BP to 13 000 BP	Botney Cut Formation	Derived Artefacts only	Exposed within Study areas the deeps
Late Pleistocene	Upper Palaeolithic/ Late Middle Palaeolithic	50 000 BP to 16 000 BP	Well Ground Formation, Bolders Bank Formation	Derived Artefacts only	Almost all of the Study Area
Middle Pleistocene	Lower Palaeolithic	420 000 BP to 375 000 BP	Egmond Ground Formation	Derived Artefacts only	May be exposed within the flanks of the Silver pit
Middle Pleistocene	Lower Palaeolithic	420 000 BP to ?	Sand Hole Formation	Derived Artefacts only	Currently only identified within the area of Silver Pit
Middle Pleistocene	Lower Palaeolithic	475 000 to 420 000 BP	Swarte Bank Formation	Derived Artefacts only	May be partially exposed in small areas close to the East Anglia Shore and in the Wash
Early Middle Pleistocene	Lower Palaeolithic	700 000 to 475 000 BP	Yarmouth Roads Formation	Derived and <i>In situ</i> Potential	May be partially exposed on the edges of Sole Pit and in small areas close to the East Anglia Shore
Mesozoic	N/A	+60 000 000 BP	Upper Cretaceous Chalk	None	May be partially exposed in small areas close to the East Anglia Shore and in the bases of some of the Pits

Table 5.2.1: Summary table for possible Hominid occupation within the Study Area.

Bowen *et al.* (2002) proposes a more restricted coverage with the ice sheet only affecting the area immediately surrounding the Humber (Figure 5.2.3). It is apparent that the glaciation would have affected most of the study area during the Devensian prior to 18 000 BP. In addition to the direct erosive power of glaciers, processes of glacial outwash would also have served to erode earlier deposits. The presence of both the Bolders Bank Formation and Botney Cut Formation within most of the study (Cameron *et al.* 1992) illustrate this. In addition the sediments re-deposited by such outwash would in other places mask earlier landscapes.

During these periods of glaciation the formation of ice sheets would have significantly lowered the sea level in the study area, leading to sub-aerial exposure. Scientific knowledge of sea levels in the area prior to the Late Pleistocene is extremely limited (Shennan *et al.* 2000) but it is likely that during the period 700 000 BP to 18 000 BP

the area would have experienced significant variations in sea level. The scale of these changes can be determined in part by examining sea level curves from other areas (see Figure 5.2.1). Whilst not taking into consideration factors such as regional eustatic uplift, these data serve to illustrate the major scale of sea level changes over the past 140 000 years. Given such physical changes, marine erosion of archaeologically significant materials and artefacts and other taphonomic processes are likely. Flemming (2002: Section 2.12) observes several factors which favour archaeological survival during inundation: the critical period for survival of archaeological deposits is when the surf zone impacts on the site and during the few hundreds of years after, when the site is in shallow water. Factors which favour archaeological survival include:

- Very low beach gradient and offshore gradient so that wave action is attenuated and constructional in the surf zone.

- Minimum fetch so that wave amplitude is minimal, wave length is short, and wave action on the seabed is at a minimum.
- Original deposit to be embedded in peat or packed lagoonal deposits to give resistance and cohesion during marine transgression. Drowned forests and peats are good indicator environments.
- Where deposits are in a cave or rock shelter, roof falls, accumulated debris, concretions, breccia, conglomerate formation, inundation by wind-blown sand, may all serve to secure the archaeological strata.
- Local topography contains indentations, re-entrants, bays,

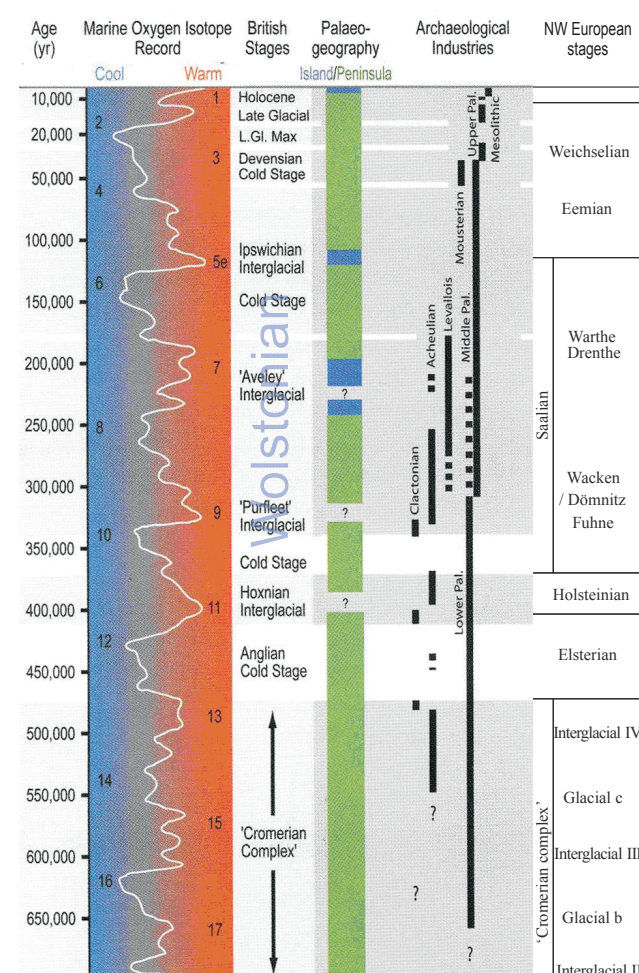


Figure 5.2.2: Palaeogeography and oxygen isotope record with reference to glacial interglacial cycles and cultural periods. Redrawn after Stringer 2006 and Gibbard *et al.* 2007.



Figure 5.2.3: Proposed extents of the last glacial maximum after Boulton *et al.* 1991 and Bowen *et al.* 2002.

estuaries, beach-bars, lagoons, near-shore islands, or other localised shelter from dominant wind fetch and currents at the time of transgression of the surf zone.

It is apparent therefore that the survival of an archaeological deposit during transgression depends heavily upon the local topographic conditions. Maps produced for these earlier periods are of a coarse resolution (e.g. Shennan *et al.* 2000), and thus determination of archaeological survival for these earlier periods is problematic. If the above is considered in conjunction with the extensive evidence for glaciation during this period it is significant that artefacts dating to the earlier Palaeolithic Periods (e.g. those prior to the Upper Late Palaeolithic) are unlikely to survive in primary contexts for most of the study area. This does not preclude artefacts and material of archaeological in secondary contexts.

5.2.2 Landscape and Climate During the Early Palaeolithic to Early Upper Palaeolithic

As observed above, the effects of climate change and sea level rise have resulted in a situation where the determination of the landscape for the Lower and Middle Palaeolithic is extremely difficult. Marine Oxygen Isotope records do provide an indication of climate during the early occupation of the study area, and is shown on Figure 5.2.2.

During the earliest stage of human occupation, the Cromerian (beginning 700 000 BP see Figure 5.2.2), the climate during the warmer phases would have been similar to that of the Mediterranean today, whilst colder phases occurred during OIS 16 and OIS 14 (see Figure 5.2.2). This landscape was favourable enough to support elephants and early species of horse and deer, all of which have been recovered from nearby in the North Sea (Kolfschoten and van Essen 2004). The existence of such species which could have formed prey to early hominid groups, aligned with a favourable

climate, would have been advantageous to human activity". The presence of evidence of hominids at *circa* 700 000 BP in Pakefield, Suffolk (Parfitt *et al.* 2005) is one such example. One of the major known features of the landscape at this time would have been the River Bytham (see Figure 5.2.4) and the river Ancaster. The Bytham drained from the southwest Midlands and the Pennines through Warwickshire and parts of Leicestershire before turning south through mid-East Anglia and eventually eastwards into what is now the North Sea but was then dry land. The river was probably one of the most important routes of colonisation for Britain's first human inhabitants.

At the beginning of the Anglian glaciation, the climate deteriorated and glaciers covered most of the landscape, whilst southern areas of Britain would have been connected to Europe due to the reduction in sea levels. Glacial processes affected large tracts of Britain, whilst the remaining area was a Periglacial landscape drained by rivers. The net result was an extensive reworking of the Cromerian landscape, and it is during this period that the drainage system of the River Bytham was destroyed, and the position of the Thames displaced towards its present course. It is also during the end of this glaciation that the land links to Europe are first breached.

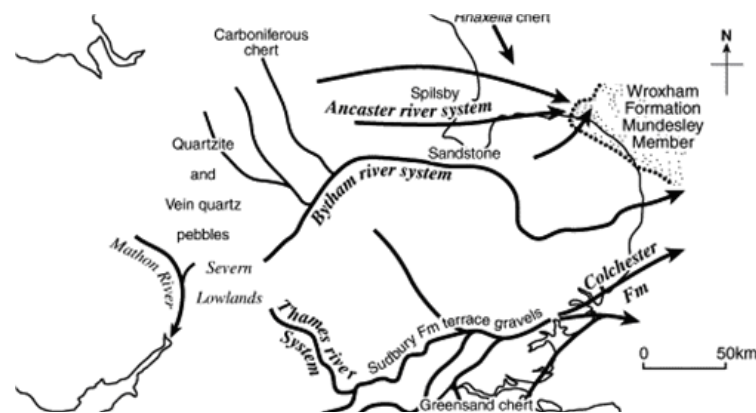


Figure 5.2.4: The Bytham River and Ancaster River after Rose *et al.* 2001.

During the controversial 'Wolstonian' period and the later Devensian glaciation the study area would have again become ice covered with many other parts of Britain becoming a peri-glacial landscape. These glaciations, like the earlier Anglian, reworked

the landscape and altered the course of rivers. Breaching of the land links would have again occurred at various intervals as shown on Figure 5.2.2. Due to these changes and the erosion of the past landscapes it is difficult to determine with any precision the geography of the region. The figure below shows how the landscape might have looked towards the end of the period covered by this section (Coles 1998 Figure 5.2.5).

5.2.3 Archaeological Potential During the Early Palaeolithic to Early Upper Palaeolithic

During the Hoxnian interglacial the climate was warm enough for human occupation, as evidenced by the Swanscombe Skull (Stringer 2006: 87). As observed above any archaeologically significant material is considered most likely to be derived from secondary contexts. The succeeding period which covers the contentious 'Wolstonian' has a varying potential. During cold periods (see Figure 5.2.2) a low potential for human presence is assigned due to the likelihood that the study area was covered by ice. During the warmer periods the area is assigned a higher likelihood for human presence, as sites such as Purfleet (350 000 years ago, Schreve *et al.* 2002) indicate the presence of hominins in Britain during these interglacial stages. Due to the presence of glacials after this period, it is observed that any archaeologically significant material will be derived from secondary contexts.

For the following Ipswichian interglacial it has been proposed that hominins may be absent from Britain (Wymer 1999, Stringer 2006), even though climatic conditions appear to have been suitable for occupation and sufficient prey species existed (Kolfshoten and van Essen 2004). This absence is thought to have occurred through the breaching of the land links with Europe and the formation of the Straits of Dover. Although evidence of hominins is absent in the present British archaeological record for the period 170 000 to 60 000 BP, this does not exclude the possibility that activity may have occurred. Given the evidence presently available, the potential for human material to date from this period is determined as low.

During the Devensian the climate would have been cold and it is thought that the study area may have been ice covered during this period. Human presence in the landscape occurred in other areas of Britain between 40 000 and 24 000 BP with modern humans

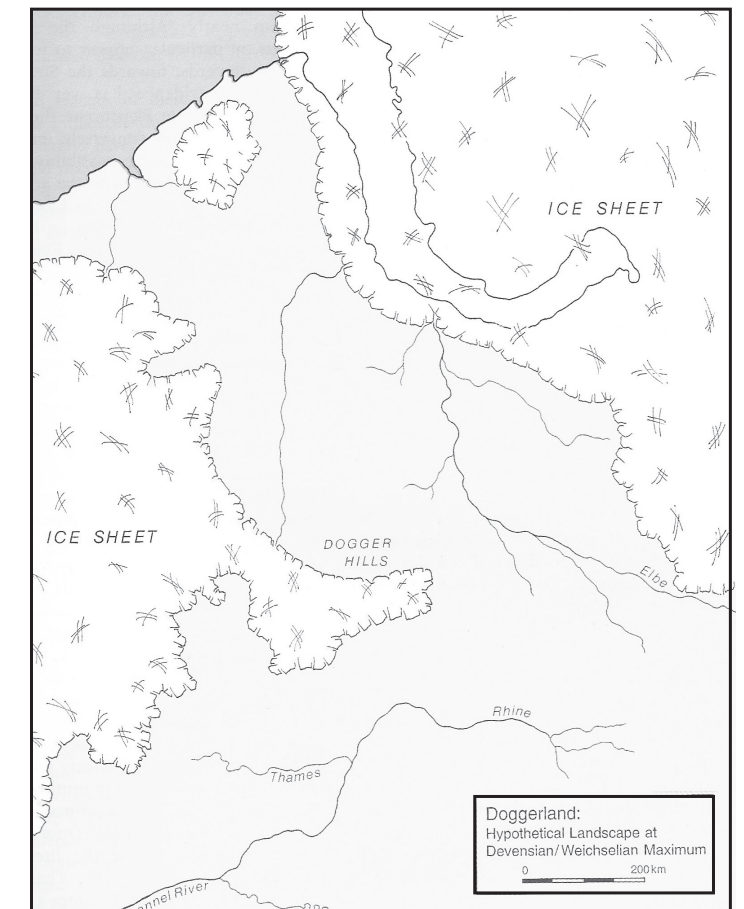


Figure 5.2.5: Doggerland — Redrawn after Coles (1998).



Figure 5.2.6: Mammoth Tusk recovered from Aggregates licence area 408 (Coal Pit) Image from Wessex Archaeology.

being recorded from around 35 000 BP. However these occupations of the landscape are regarded as relatively temporary and there is an absence of reliable evidence of human activity after 24 000 BP (Pettitt 2008). In the study area it is therefore likely that any human occupation during the period 35 000 to 18 000 BP would be ephemeral and thus the archaeological potential for this period is low. The presence of a mammoth tusk dating to 44 000 BP (Wessex Archaeology report to BMAPA 2006 Figure 5.2.6) in aggregate extraction licence area 408 illustrates that derived material dating to earlier periods may be present within glacial tills.

5.2.4 Late Upper Palaeolithic and Mesolithic Sea Level Change and Glaciation

The changes in sea level during the period 18 000 to 6 000 BP are much better understood than for the preceding periods. Lambeck (1995) shows the study area free of ice between 18 000 and 16 000 BP. Following the Late Glacial Maximum (18 000 BP) glacial rebound resulting from the removal of ice from this region caused the region to rise faster than global sea level and thus the study area remained emergent during this period.

This would have increased the amount of available land for human occupation and would also have represented the route way by which Britain would have been repopulated after the glaciation during the Late Upper Palaeolithic (Pettitt 2008: 34). The low lying landscape located within the study area would have been highly attractive to hunter gathers as it offered a range of valuable food and other resources (Coles 1998).

Whilst initially glacial rebound would have reduced the effect of relative sea level rise, as glacial rebound slowed so relative sea level rise rates increased progressively, inundating the study area throughout the period before slowing again in more recent times (Figure 5.2.7).

The use of the sea level curves provided by Shennan (2000, 2002) for this region show that the majority of the landscape was emergent from the beginning of the glacial retreat at *circa* 16 000 BP (Late Upper Palaeolithic) to *circa* 7 000 BP (Late Mesolithic) when most of the landscape was inundated. Whilst this work by Shennan *et al.* (2000) shows that inundation began *circa* 8 000 BP, it must be observed that this process was still continuing

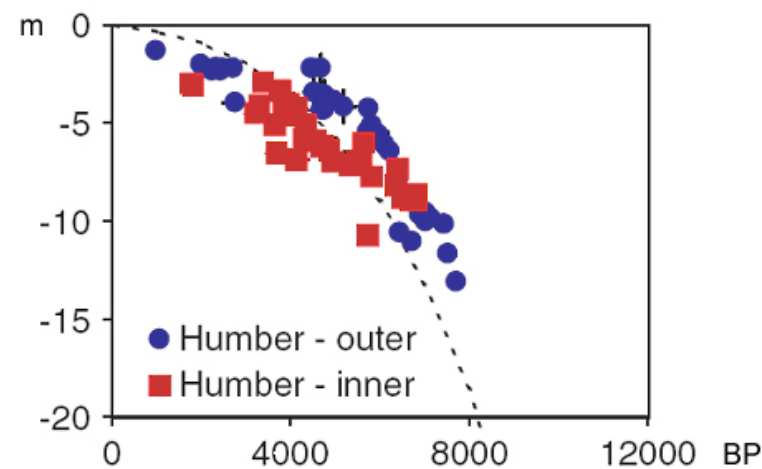


Figure 5.2.7: Sea level change in the Humber Region, calibrated age (x-axis) against change in sea level relative to present (y-axis) (after Shennan and Horton 2002).

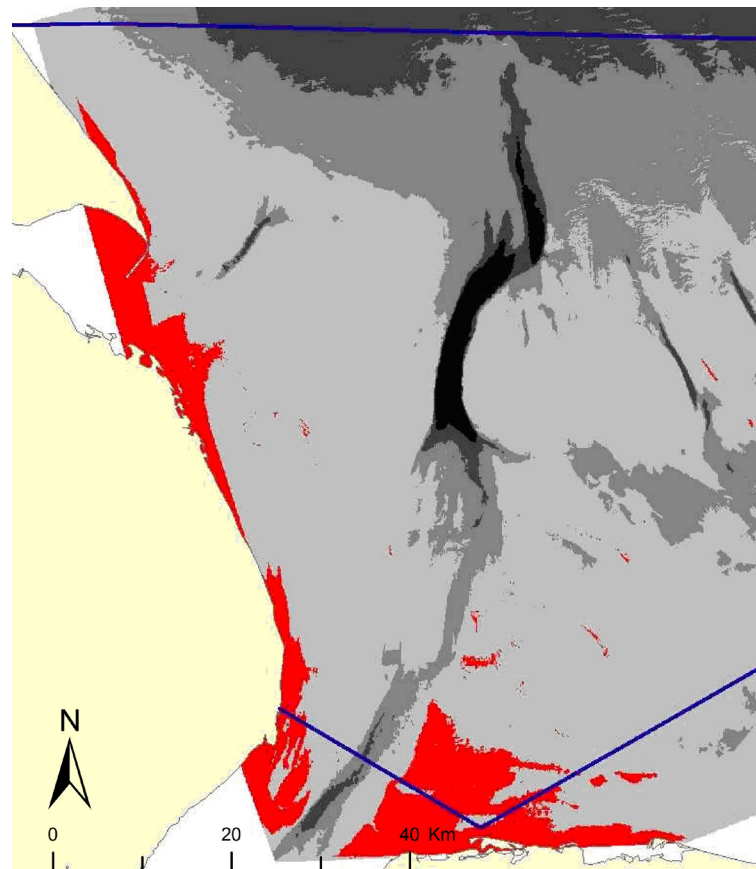


Figure 5.2.8: Areas above the -5 m contour (below present sea level) are represented here in red.

until *circa* 6 000 BP. Between these dates the landscape would have consisted of salt marshes and large intertidal flats that may have been exploited by Mesolithic peoples.

Detailed sealevel curve and estimations for tidal range for the period published by Shennan and Horton (2002) show that tidal ranges in this region for the period 6 000 BP are significantly less than that of the present day. If this is correct then their value of 3 m range may be used to determine the level of inundation. When this is applied to the value of 8 m below present sea level supplied by the sea level curves published by Shennan and Horton (2002), it suggests that the 5 m below sea level contour is perhaps the best representation for the edge of this shoreline at mean low water. Applying this value to the provided SeaZone Bathymetry in the GIS makes it apparent that the majority of the study area would have been inundated by this period. It is apparent that small but significant areas remain emergent in the extreme south of the study area and at the mouth of the Humber Estuary which were probably salt marshes. Previous research suggests that it is only by the early Neolithic that the entire study area can be considered to be inundated entirely (Coles 1999 Figure 5.2.8).

5.2.5 Landscape and Climate During the Late Upper Palaeolithic to Mesolithic

At the beginning of the Late Upper Palaeolithic, around (18 000 BP) the study area was still covered by ice sheets. At around 13 000 BP the area became ice-free and was subaerially exposed, it was flooded at around 6 000 BP (see previous section). The pattern of landscape change during this period are much better understood through the work of the ALSF NSPP.

The results of this work provide an extensive understanding of the landscape throughout most of the region. However due to the lack of 3D seismic coverage there is a large portion of the extreme western section of the Study area for which data is lacking. Significantly in this region BGS mapping and the environmental impact assessments from aggregate extraction suggest that there are few thick deposits present (Cameron *et al.* 1992, Flemming 2002: 15), with those that do survive being related to incised (e.g. erosional) features. This indicates that the original landscape has been significantly affected by processes of erosion and thus determination of the

previous landscape characteristics are problematic. Within the region covered by the NSPP our understanding of the broad scale landscape is nevertheless fairly good. Several features relating to the glacial outwash plains formed by the melting ice sheets can be observed in the southern areas of the NSPP, and may relate to the Late Upper Palaeolithic landscape.

The Mesolithic landscape within the study area investigated by the NSPP appears to have been a relatively low lying plain, sloping gently upwards towards the modern shoreline. Several minor topographic changes can be seen at the edge of the NSPP study area which would have provided a degree of higher relief within the landscape, but most of the major topographic changes are outside of the study area and located to the north. During the Early Mesolithic the landscape would have been relatively dry and well-wooded. However throughout the Mesolithic increasing sea level rise would have seen the inundation of the northern and western parts of the study area, initially forming marshland and tidal flats in areas of more rapid marine inundation. Such environments would have expanded across the study area throughout the Mesolithic before the landscape was entirely submerged. At the start of the Neolithic most of the study area would have been inundated with any remaining areas probably forming extensive marshlands.

Within the Mesolithic landscape there are a number of significant features of archaeological interest that can be observed. Several major palaeochannel systems crossed the study area trending south east–north west with many of the smaller channels following a similar trend (see Figures 5.4.3 and 5.6.21 below for NSPP results). These palaeochannels appear to originate from the area surrounding East Anglia and the Humber coastline although the absence of data near the coast prevents further comment. All the fluvial channels in the study area drain into the Outer Silver Pit on the northeast of study area. The NSPP observed that the area surrounding Markham’s Hole may have formed a lake during the period in question and it is highly likely that similar depressions within the study area could also have held bodies of fresh water.

Climate in the study area changed significantly between 18 000 to 6 000 BP (see Figure 5.2.9). At the beginning of 18 000 BP glacial conditions prevailed, but as the ice retreated were replaced by

periglacial conditions. The landscape initially (12 000 BP) would have had a tundra like vegetation cover comprising of herbs and dwarf shrubs such as *Juniperus communis* (juniper), *Betula nana* (dwarf birch) and *Salix* (willow). As climate ameliorated at the start of the Holocene *circa* 10 000 BP trees such as *Pinus sylvestris* (Scots’ pine), *Betula* (birch) and *Corylus* (hazel) expanded across the landscape. Around 8 000 BP other thermophilous trees such as *Ulmus* (elm) and *Quercus* (Oak) appeared, with *Alnus* (alder) and *Tilia* (lime) migrating by *circa* 7 000 BP. This vegetation cover would have been strongly influenced by the rates and processes of marine inundation. The ingress of saline waters into the forested areas would have led to forest die-back, opening up areas of the landscape, with the remaining forest cover comprising of the hardiest tree types such as *Pinus* and *Betula*.

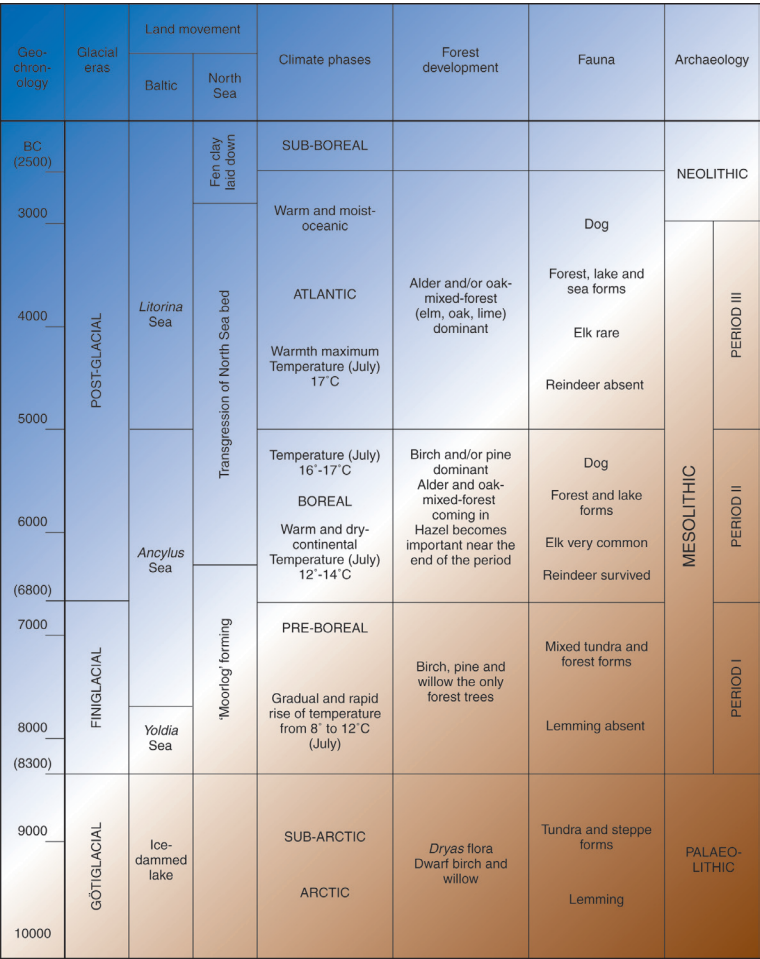


Figure 5.2.9: Environmental and climatic changes in northern Europe (© D. Smith Birmingham University).

The most important observation is that the landscape was very much a dynamic one during the period in which it was available for human occupation (from *circa* 13 000 BP). Whilst the relative topography of the area would have remained unchanged, the effects of progressive sea level rise and climate change would have dramatically altered the appearance and resources of the area in which humans would have lived.

5.2.6 Archaeological Potential During the Late Upper Palaeolithic to Mesolithic

Direct evidence for human occupation very near the study area is from the discovery of the Colinda Point (a prehistoric antler harpoon point) in September 1931 by the trawler *Colinda*. Found in a block of peat (moorlog) halfway between the two North buoys in mid-channel between the Leman and Ower, this point was radiocarbon dated to 11 740 ± 150 BP (Housley 1991). This date therefore represents the minima date of occupation in this region (Figure 5.2.10).

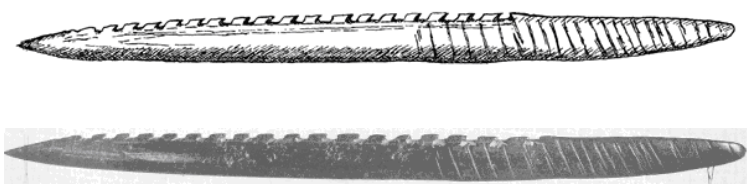


Figure 5.2.10: The Leman and Ower Point. Original photograph and drawing by H Muir Evans.

Related to this discovery are the subsequent finds of peat (moorlog) at a nearby location (Godwin 1960) which were dated to 8424 ± 170 BP and thought to relate to the landscape in which this find was located. Several similar deposits of peat are observed within BGS cores located to the south of the study area, possibly associated with the Elbow Formation (Cook 1991) and also as part of this study. The presence of these deposits within this region suggests that information relating to the emergent landscape of this period still survives. This survival of landscape is illustrated in part by an archaeological assessment performed just outside the study area

for Sheringham Shoal Offshore Wind farm, which located a series of Holocene fluvial systems and associated *in situ* deposits (Wessex Archaeology 2006: 534).

Nearer shore, there are several 'submerged forests' (peat beds preserving sub-fossil tree remains) located in the Yorkshire, Lincolnshire and Norfolk intertidal zones (Hazell 2008) in which are preserved deposits with archaeological potential. These locations are at Trusthorpe, Hartlepool Bay (Waughman 2005), Titchwell (Wymer and Robins 1994) and between Mablethorpe and Sutton on Sea. Finds of Early Mesolithic to early Neolithic material have been recovered here.

The potential character of archaeological occupation of the submerged landscape during this period is illustrated by several nearby dryland sites which provide equivalent evidence. Most terrestrial sites from this period are often only a few flint scatters, and do not represent the full range of material that may be preserved in the waterlogged deposits which may survive in the study area.

Star Carr, a key wetland site for the early Mesolithic in Britain, illustrates the range of material that could be expected. Star Carr consists of a platform of rather rough branches of birch wood and brushwood used to stabilise the contemporary reed bed and projecting into open water. The platform is radiocarbon dated to around 9 100 BC is associated with a dense scatter of artefacts including more than 14 000 stone tools, over 220 finished antler artefacts (mainly barbed antler points), bone mattocks and red deer 'frontlets' (Mellars and Dark 1998, Conneller 2004). Much of this material would not be preserved in a standard terrestrial environment, but where conditions are waterlogged and anaerobic, such organic remains can survive. The Mesolithic site of Bouldner Cliff in the Solent, a platform of Mesolithic age some 15 m below sealevel, clearly illustrates the presence of similar sites in British marine waters (Momber 2004).

Another major site which must be considered is the nearby Mesolithic site at Howick, located on the Northumberland coastline. When excavated this site revealed, in addition to a series of associated pits, a series of stains and postholes in the soil marking the presence of a circular Mesolithic timber house. The Howick Hut is some 6 m in diameter and would have had

posts supporting a steeply pitched and presumably thatched roof. Although truncated by erosion, the Howick structure still possessed accumulated floor deposits of approximately 0.5 metres, making this one of the best preserved Mesolithic dwellings ever found in the United Kingdom. The hut at Howick is a much more substantial structure than any previously discovered and radiocarbon dating of hazel nuts recovered from the site show activity to be around 7 800 BC. The discoveries at Howick arguably suggest a degree of sedentism not previously evidenced in Britain for this period. Structures such as Howick now appear to be widespread on the North East Coast during the first half of the 8th millennium BC (Waddington 2007). Given the coastal context of Howick, it is entirely probable that similar such structures could exist within the study area.

Both Howick and Star Carr illustrate that the study area has the potential to preserve archaeological sites and deposits. The current absence of any such sites in the area is considered to reflect the problems of locating and surveying the submerged landscapes in the North Sea.

5.3 Maritime Archaeology Background

5.3.1 The North Sea Seascape and Environment

The North Sea is described as essentially 'coastal' in its outlook by Kirby and Hinkkanen (2000), and has a very rich history, formed both by its unique environment, and its relation to the cultures and populations that inhabited its borders (Kirby and Hinkkanen 2000). The North Sea is approximately 530 000 km² in area, and is generally defined as the waters between the Straits of Dover and a line from Scotland and the Northern Isles to Norway (Kirby and Hinkkanen 2000, 11). The study area is central in this, and adjacent to the east coast of England. The Humber Estuary lies directly to the west, and the Wash is to the southwest.

The relatively mild climate of the North Sea is due to the warm waters of the Gulf Stream and the westerly winds off the Atlantic (Kirby and Hinkkanen 2000, 14). However, the region is also prone to squally rain and storms, especially in the winter months, and storm surges including rises in sea level, caused by violent winds and sudden falls in atmospheric pressure occur especially around the new or full moon when the spring tides have their

greatest range and force (Kirby and Hinkkanen 2000, 14). Kirby and Hinkkanen note that a deep depression that swept into the North Sea in 1953 raised the mean sea level by over half a metre, and that the force of the winds generated waves up to 12 metres high.

The Wash, to the south of the study area, may have been considerably larger in Roman times, although while coastal erosion has affected the cliffs along Holderness and the East Anglian coast, the contours of the area have changed little over the last 300 years (Kirby and Hinkkanen 2000, 9). Certainly the medieval sea defences identified on the NMR are substantially farther inland.

The area has seen a substantial amount of shipping related to coastal trade, international trade, fishing, and the affairs of the military. The seas in the area, and the waters of Northern Europe in general, were renowned for their stocks of fish. The shoals of herring off the Scanian coast were something of a medieval legend, highlighted by the Swedish cleric Olaus Magnus.

The nature and character of the seabed within the study area contributes greatly to its maritime history. The shoals, sandbanks and sand waves within the southern North Sea are hazardous to navigation, and are most dangerous after periods of relatively calm weather or neap tides. These sand waves are formed where the water moves rapidly over areas of unconsolidated seabed sediment. (Admiralty Sailing Directions 2006).

Navigation of the River Humber has always been considered difficult, again due to the underlying nature of its bed. It is described as tortuous in character, with moveable matter within which the waters are charged, the navigable tracks passing between numerous shoals and extensive flats. The tidal streams are rapid and irregular, and can change direction between spring and neap tide (NSP 1858).

The efforts made throughout history to increase the safety of passage through the Humber, include lighthouses and beacons, buoys and lightships, though there are frequent changes in the channel of the Humber (between Hull and Goole for instance) (NSP 1858, 85). The constant movement of tides, seas and sandbanks increases the hazards for shipping considerably and around the Humber area, conventional lighthouses could not be used. The

first active petition for a lightship came in 1679, but it was not until 88 years later that the Humber received its first floating light vessel (<http://www.hullcc.gov.uk/museumscollections/collections/subtheme.php?irn=7>).

Navigational hazards around the mouth of the Humber include Stone Banks, or Binks, which are connected with Spurn point and composed of shingle and sand. These are named Outer, Middle and Inner, and are described in 1858 as partially uncovered at low water springs. A narrow channel is sometimes formed between the Inner banks and Spurn point, but is only fit for vessels of light draught (NSP 1858).

Of the other navigational hazards in the area, Chequer Shoal is a patch of stony ground, Sandhaile is an extensive sandy flat projecting from the Lincolnshire coast and forming the southern boundary of the entrance to the Humber (NSP 1858, 87).

The entrance to the Wash, or Lynn deep, is also described as occupied by numerous and dangerous sands, with rapid tides rendering this the most difficult portion of the navigation on the eastern coast (NSP 1858, 98). There are several dangers to navigation in this area, including the Protector Overfalls, a ridge of sand extending north-south for approximately 2 miles, and described as a significant obstacle to vessels proceeding from the Humber to Lynn Deep (NSP 1858, 99). Inner Dowsing is also an extensive shoal, described as in the fairway of vessels bound to Lynn Deep (NSP 1858, 99).

For a maritime power such as Britain, the sea was the key to national prosperity and security (Kirby and Hinkkanen 2000, 22). The influence of the sea in the past extended much further inland, with major cities being founded on navigable rivers and watercourses (Kirby and Hinkkanen 2000, 23). In the study area, the navigable rivers that flow into the Humber and thence into the study area include the River Trent and the River Ouse, on which the medieval city of York sits.

Whilst the extent of how far these rivers were navigable during the medieval period is a matter of some dispute and there is possibly a decline in the extent of these river networks during the later middle ages (Jones, 2000), these rivers were navigable and provided a vital form of transport and communication with urban areas inland to the coasts. As the population and economy of Britain grew during

the post-medieval period, and the numbers and volume of ships and cargo increased, so did the need to maintain these waterways.

It is in part, the large watercourses of the Trent and the Ouse flowing into the Humber, that contribute to the dangers of navigating this stretch of water. Flooding inland has been known to disturb the seabed, and the sandbanks are particularly difficult to navigate. Since the post-medieval period at least, substantial efforts have been made to ensure the safety of ships, with the construction of lighthouses on land. In areas where shoals and sandbanks are too far from the coast, light boats were employed to guide mariners through these potentially treacherous waters.

The importance of the Humber during the 16th century is highlighted by the construction at this time, of a lighthouse at the entrance to the estuary. Such undertakings were costly, and only built at vital points on the main trading routes. Efforts were made to aid the task of navigation by the provision of buoys, markers and lights, although navigation still relied heavily on the coastal contours and prominent landmarks (Kirby and Hinkkanen 2000, 65). The changing nature of the seabed in the study area would have proven hazardous even to the most experienced navigator.

5.3.2 Causes of Wrecking and Volume of Shipping

In addition to natural hazards, wrecking incidents can be attributed to a variety of causes. These include accidents, storms, collisions and enemy action during periods of conflict. While these causes might threaten all maritime activity during any period, there is some element of individual character that might be regarded as specific to the study area itself.

The general North Sea region has a record of storminess that has created innumerable shipping disasters and impacts on the coastlines. The North Sea is also possibly one of the busiest shipping regions in the world, surrounded by densely populated countries (Lamb 1991). Whilst storms at sea are frequent, there have been periods in which storms have been more prevalent and severe. Lamb notes 'impressive climaxes of storminess' in the region between 1570–1620, between 1690 to early 1700's and in the 1790's. Some of the most intense storms and lowest pressures are noted in the 1880's and 1890's (Lamb 1991, 33). These storms caused many wrecking incidents, with gales and waves causing ships to spring leaks, collide and founder.

The earliest storm identified from this research was one that dispersed the Danish fleet in the 11th century and is described briefly but without exact information as to location in the Anglo-Saxon chronicles (Garmonsway 1953, 204–7).

The storm over the whole of the North Sea in November 1570 which became famous as the 'All Saints Flood' is suggested not to have affected the shores of England, though the English coast had already been struck by surges in the preceding month, and the whole of western Europe had been troubled by floods for much of the year (Lamb 1991, 38).

Documentary records from between 1570 to 1668 describe exceptionally strong and stormy winds, that caused great quantities of sand to be transported inland in areas of East Anglia, ruining estates, and impacting significantly on landowners in the area (Lamb 1991, 39). Records relating to the Spanish Armada note storms in August and September of 1588 (Lamb 1991, 55).

There are also records of exceptional weather in September 1695. Lamb suggests that it is this storm described by Daniel Defoe. Defoe describes how a fleet of some 200 colliers were driven ashore near Winterton Ness, Norfolk. Some tried to get to Lynn Deep, but 140 were driven ashore and, counting other vessels from Lyn, Wells etc, some 200 ships may have been lost (Lamb 1991, 56). Strong storms are also recorded in September and October 1697 (Lamb 1991, 57).

It is the Great Storm of 1703 which may have caused the most damage both at sea and on land during this period of history. Lamb (1991), citing Short (1749), reports that 'England lost more ships in this storm than ever were lost in any encounter with an enemy' and suggests that of over 1500 men perished. Other reports suggest that one third of all the seamen in the navy (around 10 000) were lost in this storm. There were reports that buildings and sea walls were destroyed, including damage to three cathedrals whilst whirlwinds are reported, such as that at Whitstable in Kent where a ship was lifted out of the water and deposited 250 m from the waters edge (Lamb 1991, 59). Descriptions of the storm and its aftermath were written about by Daniel Defoe, in 'The Storm'. Defoe describes in general the effect the storm had on shipping:

'I might call it a damage to trade, that this season was both for some time before and after the tempest, so exceeding and so continually stormy, that the seas were in a manner unavigable and negoce, at a kind of a general stop, and when the storm was over, and the weather began to be tolerable, almost all the shipping in England was more or less out of repair, for there was very little shipping in the nation, but what had received some damage or other...' (D.Defoe 'The Storm', 1703).

Defoe further notes casualties to ships and shipping, including ships lost at sea and collated letters from around the country describing the storm from local perspectives. It is from these letters that records of wrecking incidents are derived. One of these was a letter from Thomas Little of Lynn, who reported the loss of 7 ships from that port with loss of 20 lives. Worse was recorded in Grimsby by Thomas Fairweather, who wrote that of a fleet of 100 vessels, 50 were 'wanting' after the storm. Casualties were recorded but not quantified in this letter. Another letter describing the storm in the Humber region relates a similar story, suggesting that among the ships in the area were colliers from Newcastle, and numbers of the Russian fleet that had sought haven a few days earlier:

'..for the great mischief was done in the night, which was so pitch dark that of above 80 ships that then rid in the Humber, about Grimsby Road, very few escaped some loss or another, and none of 'em were able to give a relation of any body but themselves.'

The letter also describes an account of the storm from the perspective of the lighthouse keeper at Spurn, Mr Peter Walls

'He did verily believe that his Pharos (which is above 20 yards high) wou'd have been blown down; and the tempest made the fire in it burn so vehemently, that it melted down the iron bars on which it was laid, like lead...and then Peter Walls observed about six or seven and twenty sail of ships all driving about the Spurn Head, some having cut, others broke their cables, but all disabled, and render'd helpless. These were a part of the two fleets that then lay in the Humber, being put there by stress of weather a day or two before, some from Russia, and the rest of 'em colliers, to and from Newcastle. Of these, three were dirven upon an island call'd the Den, within the Spurn, in the mouth of the Humber...'

As can be seen from the records of documented wrecks within the study area, collisions with other vessels were common, especially during the 18th and 19th centuries. This in itself highlights the area as the entrance to important trading ports during the period, and the huge volume of shipping in the general area.

Even from the medieval period, the need to adhere to safe shipping lanes and passages would have increased the risk of collision because of the concentration of traffic through confined spaces. Significant numbers of vessels passed through the area from an early date, including colliers carrying coal from Newcastle to London from the 17th century.

There was roughly an 18 fold increase in shipping tonnage entering the port of Kingston upon Hull between 1716 and 1793. Despite opposition from merchants who used the old staithes and piers as opportunities for customs evasion, they supported the Dock Act 1774. The town had 3 docks by 1829, and a volume of traffic around 40 times greater than the preceding century (Kirby and Hinkkanen 2000, 81). It was written that 'the entrance to the haven was so overcrowded that it was said that it took less time to sail from St Petersburg than it did to thread through the keels and rafts in the river Hull' (Kirby and Hinkkanen 2000, 81).

The volume of shipping from the Humber docks was substantial. 4 348 vessels are recorded as having arrived in the port of Hull in 1856, with a total of 806 175 tons (NSP 1858, 84). By 1872 records show that 4 867 vessels arrived, with a total of 1 471 013 tons, demonstrating a significant rise in the size of the vessels, as well as an increase in their numbers (NSP 1874, 89).

The intensely competitive nature of transporting cargo by sea also means that deliberate collisions between rival merchants and ships were not unheard of. Evidence for this is seen in the newspaper reports of the time, where articles and letters refer to legal action taken against their perpetrators of the incidents.

There are also incidents recorded that suggest that 'privateering' took its toll on the shipping in the area. Privateering was prevalent during the medieval period, at times encouraged by the establishment as a legitimate endeavour. Within the study area, it was the Dunkirk pirates that were feared during the 17th century, frequently attacking the Newcastle to London coal trade (Kirby and

Hinkkanen 2000, 120). 18th century wrecks documented on the NMR such as that of the *Hopewell* of Harwich also tell of the threat of privateers.

It is, however, during WWI and WWII that the human threat to shipping becomes a greater danger than the natural hazards faced by previous mariners. The vast majority of wrecks in the study area during the period 1914-1918 were caused by mines, or submarines, and likewise this is the case also during WWII, with the additional threat from bombing by German aircraft. The Defence of Britain project demonstrates the level of coastal defence against attack in the area (Figure 5.3.1).

The war in the air over the study area was not only involved with attacks on shipping from below. German bombers flying overland aiming for the cities and airbases, and British and American fighters aiming to combat the threat, or returning from their own bombing raids on the continent, also contribute to the wrecks in the study area.

5.3.3 History of Maritime Activity in the North Sea/Humber REC Study Area

Bronze Age

The east coast of Britain, notably the Humber Estuary, has produced some of the earliest examples of Bronze Age ships and shipping in North East Europe. Boats constructed of sewn planks, along with paddles and other possible boat components at North Ferriby date from the early Bronze Age to the Iron Age and suggest that complex composite boats were being constructed and used during this period (Chapman and Chapman 2005). Other remains in the area include a boat plank found at Kilnsea dated to 1750–1620 cal BC (Van de Noort 2009, 163), and a sewn plank boat from Brigg, dated to *circa* 825–760 cal BC (Chapman and Chapman 2005, 170). The boats at Ferriby dated to the Bronze Age were constructed from *Quercus* (oak), and 'sewn' together using *Taxus* (yew) withies. Ferriby 4, dated to the early Iron Age, comprised a single *Alnus* (alder) plank (Chapman and Chapman 2005). There is debate as to whether the boats were constructed for local voyages across and up the Humber (McGrail 1987) or for longer cross-channel voyages and therefore for international trade (Van de Noort 2004). It is possible that the Humber coastal area would

have been used by boats trading Whitby jet to the south coast and the continent (Needham 2009, 27 Figure 2.7d).

Iron Age and Roman

It has been suggested that, in societies ruled by warlords and chieftains, long distance trade was primarily in luxury and prestige goods that served the interests of the elite (Kirby and Hinkkanen 2000). Controlling this trade was important, and led to the establishment of specific trading places from which goods were further distributed. The location of ports in sheltered places, away from the open coast, were chosen for their suitability for regulating and controlling this exchange (Kirby and Hinkkanen 2000, 104).

Cunliffe (2009, 88) suggests that maritime contact was maintained during this period along the whole of the coast between Yorkshire and Dorset, again carrying amongst other things, Whitby jet.

Maritime activity in the area is indicated by the high concentration of Iron Age gold torcs found in the north and west of Norfolk, which suggests trade in the area around the Wash (Wessex Archaeology 2007).

The boats of this period were possibly initially constructed from hide, a technology which was well established in northwestern Europe, and used by the seafaring Celts (Woodman 1997). A boat found in 1921 in a bog in Denmark was dated to around 350 BC and was constructed from wide *Tilia* (lime) planking sewn together to create a hull over 50 feet long. There is little evidence for the adoption of oars until about AD 350, shown by the Nydam ship of this date, also recovered from a bog in Denmark (Woodman 1997, 23–5).

Woodman (1997, 23) notes that Julius Caesar commented that the Celtic ships were 'built and rigged in a different manner from ours' and suggests that the galleys of the Romano-British Saxon Shore were likely fitted with sails (Woodman, 1997, 26). It is also from Julius Caesar that the first documented use of log rafts in North West Europe is obtained, as he noted that the Celtic tribes used them to cross rivers (McGrail 1987, 54).

Roman maritime activity in the study area can be inferred from the construction of Saxon Shore forts, such as that at Brancaster on the southeastern shore of the Wash, constructed in the 3rd century AD, and other forts at Skegness and Brough-on-Humber. Although

there is debate on the purpose of these forts, their presence attests both to the threat of invasion by sea, and to the seafaring activities of the Romans at the time (Johnston 1997, Pearson 2005).

Anglo-Saxon and Viking

The Humber region is mentioned several times in the Anglo-Saxon Chronicle, highlighting both its importance, and the importance of seafaring during this period.

Archaeological evidence for the importance and significance of seafaring during this period is also evident from the well known boat burials such as at Sutton Hoo. The Sutton Hoo burial ship was built during the 7th century and, as well as the remarkable treasures associated with it, had a more complex construction than earlier long boats. The ship was around 90 feet long, with a depth of hull of 4.5 feet. Propelled primarily by oar, it is unclear whether these early long boats also had sail, though they would have known about them, as the galleys of the Romano-British Saxon Shore would have been fitted with them (Woodman 1997, 25–6).

The date of the adoption of sail in the long ships is uncertain, though it is likely that the tempestuous nature of the North Sea encouraged the adoption of this innovation. Certainly by the time of the Viking invasions around AD 800 the evidence suggests the ships were of a sturdy merchant hull which was sail propelled (Woodman 1997, 27).

An entry in the Anglo-Saxon Chronicles for 865 AD tells of how a great host came to England and wintered in East Anglia, while in 866 AD this host went from East Anglia, over the mouth of the Humber to York, causing 'great dissension' (Garmonsway 1953, 68–69). In 942 AD the Humber river is described as '*that broad ocean stream*' in an entry describing King Edmund conquering Mercia (Garmonsway 1953, 110–111).

Sea battles are mentioned in 991 AD when it was decided for the first time to pay tribute to the Danes due to the 'great terror they inspired along the sea coast'. In 992 AD the king called all ships of value to London, with instructions 'to entrap the host somewhere out at sea'. In the first instance the host got away, but were then engaged by ships from East Anglia and London. In 993 AD the Chronicles tell of Banburgh being destroyed, and the

host coming to the mouth of the Humber and 'doing damage there' (Garmonsway 1953, 127).

The Danish invasion in 1013 is also documented in the chronicles, describing how King Swein sailed first to Fleet, then around East Anglia to the mouth of the Humber, then along the Trent (Garmonsway 1953, 143).

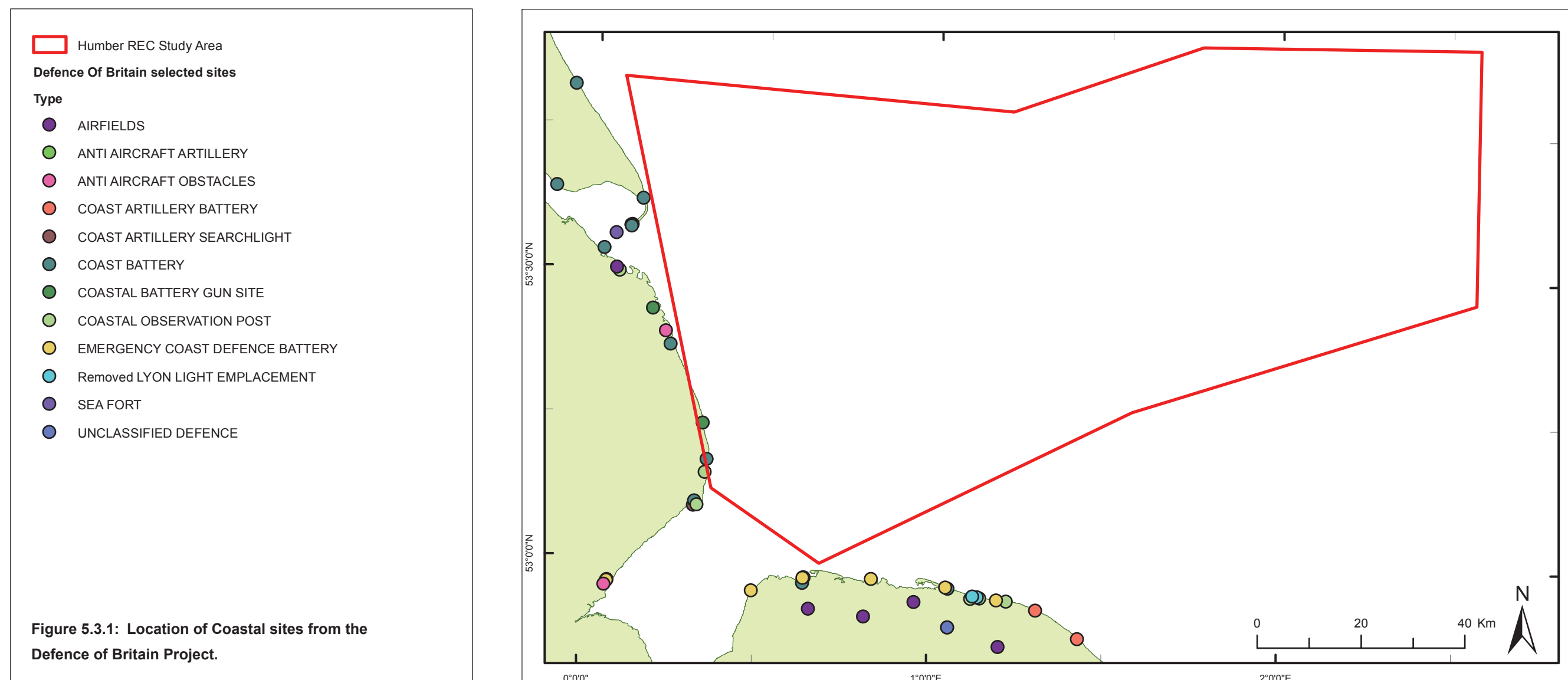
Later entries include those around the time of the Norman invasion. In 1066, Harold had succeeded to the kingdom of England, and William of Normandy had invaded. The chronicle of this year tells that:

'Meanwhile Earl Tostig came into the Humber with sixty ships, and earl Edwin came with land levies and drove him out, and the shipmen deserted him. He sailed to Scotland with twelve small vessels, where he was met by Harold, the Norwegian king, with three hundred ships, to whom Tostig gave allegiance. Together they sailed into the Humber until they came to York, where earl Morcar and earl Edwin fought against them, and the Norwegian king gained the victory.' The Laud Chronicle 1066 (Garmonsway 1953, 197).

Even after the successful Norman invasion, England was not safe from the Danish marauders. The chronicles also record that in 1070 three sons of King Swein sailed from Denmark into the Humber with two hundred and forty ships, and forming an immense host, they advanced on York, destroying the castle. It is said that the troops lay all winter in the Humber, where the king could not reach them. When King William and King Swein came to terms, it is recorded that the Danes left Ely laden with treasures, though when they were at sea, a great storm arose and the ships were scattered (Garmonsway 1953, 204–207).

In 1075 another Danish expedition to York was successful, and in 1085 parts of the east coast of northern England were devastated by King William in an attempt to hinder any invasion threatened by Knud the Holy of Denmark (Kirby and Hinkkanen 2000, 109).

Although the precise location of Viking landings is not known, artefactual evidence of their activity has been found in rivers accessible from the North Sea at Blakeney and Wells-next-the-Sea (Wessex Archaeology 2007).



Medieval Period

The political character of the early medieval period, with loosely united European kingdoms under the authority of the Pope and the Roman Catholic Church, created a degree of stability that encouraged trade, but also spawned religious wars. Both factors had effects on maritime history of the ship, creating the need for the transport of armies for the crusades and goods for trade (Woodman 1997, 37).

The Norman conquest in 1066 established new trade links. The new gentry disliked the Saxon produced ale and mead, and the wine trade flourished (Woodman 1997, 47). The trade in wine

continued throughout the medieval period, with Hull ranked second or third in England as an entrepot for this commodity, which was generally the return cargo in a two-way trade for cloth and food (Kermode 1998, 177). Yorkshire had been a textile manufacturing region before the expansion of the industry in the mid-14th century, which also became a major export commodity (Kermode 1998 173). Cloth exports from Hull grew rapidly during the mid- to late-14th century, though the port still lagged behind London and the south coast ports (Kermode 1998).

The character of maritime activity in the area is in many ways shaped to its position within the extensive foreign trade network

formed by the Hanseatic League. The Hanseatic League was established in Lubeck in 1169, in order to protect against both pirates and extortionate tariffs and dues levied by princes. The expansion of the league was to encompass some 84 cities (Woodman 1997, 44). The English cities included Kingston-upon-Hull and King's Lynn, in Norfolk to the south of the study area. In terms of duties, Lynn was amongst the highest of any of the south or east coast port, although the town had declined by the 15th century (Wessex Archaeology 2007).

The increase in commerce and the upheavals caused by the crusades drove the development of the ship during this period

towards the 'full-rigged ship' which emerged around 1550. This became the dominant type, and remained essentially unchanged for three centuries when it finally was superseded by the development of the steamship (Woodman 1997, 38).

During the medieval period, kings relied primarily on merchant ships and sailors when the need arose, often dispatching royal officials to ports to requisition suitable vessels and crews, though there were attempts to build up a royal fleet. Edward III was one of the kings that attempted to build up a royal fleet, and during the siege of Calais, 11 ships and 170 mariners were furnished by Grimsby (NSP 1858, 82).

Piracy at the time was ill defined in terms of legality, as privateering was both condemned and condoned dependant on circumstances. Henry VIII created an act against piracy in 1535, yet during the reign of Elizabeth I, after the defeat of the Spanish Armada, the rewards of privateering possibly contributed up to 15% of England's total imports (Kirby and Hinkkanen 2000, 120). It remained generally a menace during this period and that of the early post-medieval period, even after the creation of permanent state navies (Kirby and Hinkkanen 2000, 118-9). Within the study area, it was the Dunkirk pirates that were feared during the 17th century, frequently attacking the Newcastle to London coal trade (Kirby and Hinkkanen 2000, 120).

Post-Medieval

Records such as the calendars of British state papers illustrate the amount of governmental business taken up with naval and maritime affairs during this period (Kirby and Hinkkanen 2000, 22).

Of the ports along the Humber, Kingston upon Hull was one of the earliest, and by 1858 described as 'a place of the first mercantile importance: it has gradually risen to be the third port in the kingdom for its foreign trade, while it is without a rival in the amount of its inland traffic' (NSP 1858, 83). The port is linked to the interior via the rivers Hull, Derwent, Ouse and Trent, and by railways such as the Hull and Selby Railway formed in 1840. It was a chief inlet for corn, linseed, cotton, rapeseed, timber, wool, flax, hemp, iron, madder and rags, and was described as having steam communication with a range of European ports including Antwerp, Boulogne, Copenhagen, Riga and Stockholm. (NSP 1858, 84, Figure 5.3.2).

There was a roughly 18 fold increase in shipping tonnage entering the port of Kingston upon Hull between 1716 and 1793. Despite opposition from merchants who used the old staithes and piers as opportunities for customs evasion, they supported the Dock Act 1774. The town had a volume of traffic around 40 times greater than the preceding century by the early 19th century (Kirby and Hinkkanen 2000, 81). Kirby and Hinkkanen state that 'the entrance to the haven was so overcrowded that it was said that it took less time to sail from St Petersburg than it did to thread through the keels and rafts in the river Hull' (Kirby and Hinkkanen 2000, 81).

Several docks were constructed at Hull. The Old Dock is dated to 1778, the Humber Dock in 1809, The Junction Dock in 1829, The Railway Dock in 1846, and the Victoria Dock in 1853 (NSP 1858, 84 Gillet and MacMahon, 1980).

Historically Grimsby was also an important port during the medieval period, though the harbour became choked with sand, and the trade was absorbed by Hull. It was not until the construction of a dock in 1801 that the trade of the port revived (Gillet 1970) (NSP 1858, 82).

Goole was also an important trading port during this period, connected by canal and railway to the large manufacturing towns and districts, with trade principally of exports of coal, lime, salt, wool, cotton and iron, and imports of cattle, corn, timber and general merchandise (NSP 1858, 85).

The infrastructure that linked these ports to the industrial hinterland was also important. The early links were by navigable rivers and during the post-medieval period these were maintained, as well as canals and railways adding to the means by which imports and exports could be transported. In 1790 the canal engineer William Jessop reported on the state of the River Ouse and suggested that there were not more than three seagoing craft a week going above Selby and that this figure included Hull Sloops and small vessels from Gainsborough and Rotherham <http://www.jim-shead.com/waterways/sdoc.php?wpage=PNRC0001>

From an early date, coal was possibly one of the most important cargoes to pass through the study area, as an import to and from the numerous ports on its' edge carried by colliers passing through from Newcastle to London. Wine was still a valuable import, though

by 1600 the greatest import to Lynn was coal. In 1701, 75 000 tons passed through the port, which increased to 170 000 tons in 1801 (Barney 1999).

4396 colliers reached London in 1795, a number which had increased to over 9 000 by 1837 (Wessex Archaeology 2007). The ships used at this time were mainly collier brigs and smaller sloops and smacks (Barney 1999).

It was during the later post-medieval period that new developments to ship construction occurred. There was the change from sail to steam power and the use of iron in the construction of the hull. These larger, more reliable ships could carry more cargo and travel further than their wooden, sail- powered, counterparts. Another change, at the end of the 19th century, was the adoption of steel rather than iron in manufacturing, which being lighter than iron increased the volume of cargo vessels could carry.

The development of the steam powered ship did not mean the instant demise of the sailing vessel, indeed throughout the 19th century the sailing ship thrived, especially the tea, wool and passenger clippers, and sail was still being used and developed into the 20th century (Woodman, 2005, 175). Steam itself developed from paddle propulsion to screw propulsion, which itself led to the development of iron hulled ships that could take the new stresses and strains of this new technology (Woodman, 2005,185), and the adoption of steel, which took up to 40% gross tonnage as opposed to 50% in the case of iron, also allowed larger ships to be constructed (Woodman, 2005).

International trade during the post-medieval period flourished, with ships travelling all over the world carrying various types of cargo. One such cargo, found from all over the globe, are metal ingots. In 1991, a number of lead ingots were found on a wreck on the East Coast of India. Some of these were marked W: Blackett, and research identified that their source was the lead mines of the North Pennines. Further research showed that W Blackett was a well known lead-exporting company in England since 1694, with products exported all over the world up until after the 18th century. Merchants marks on these particular ingots suggests that they had changed hands before their final voyage, though they are still indicative of international trade during this period, and the dates stamped on them have helped give a provisional age for the wrecking (Tripathi *et al.* 2003). Similar lead

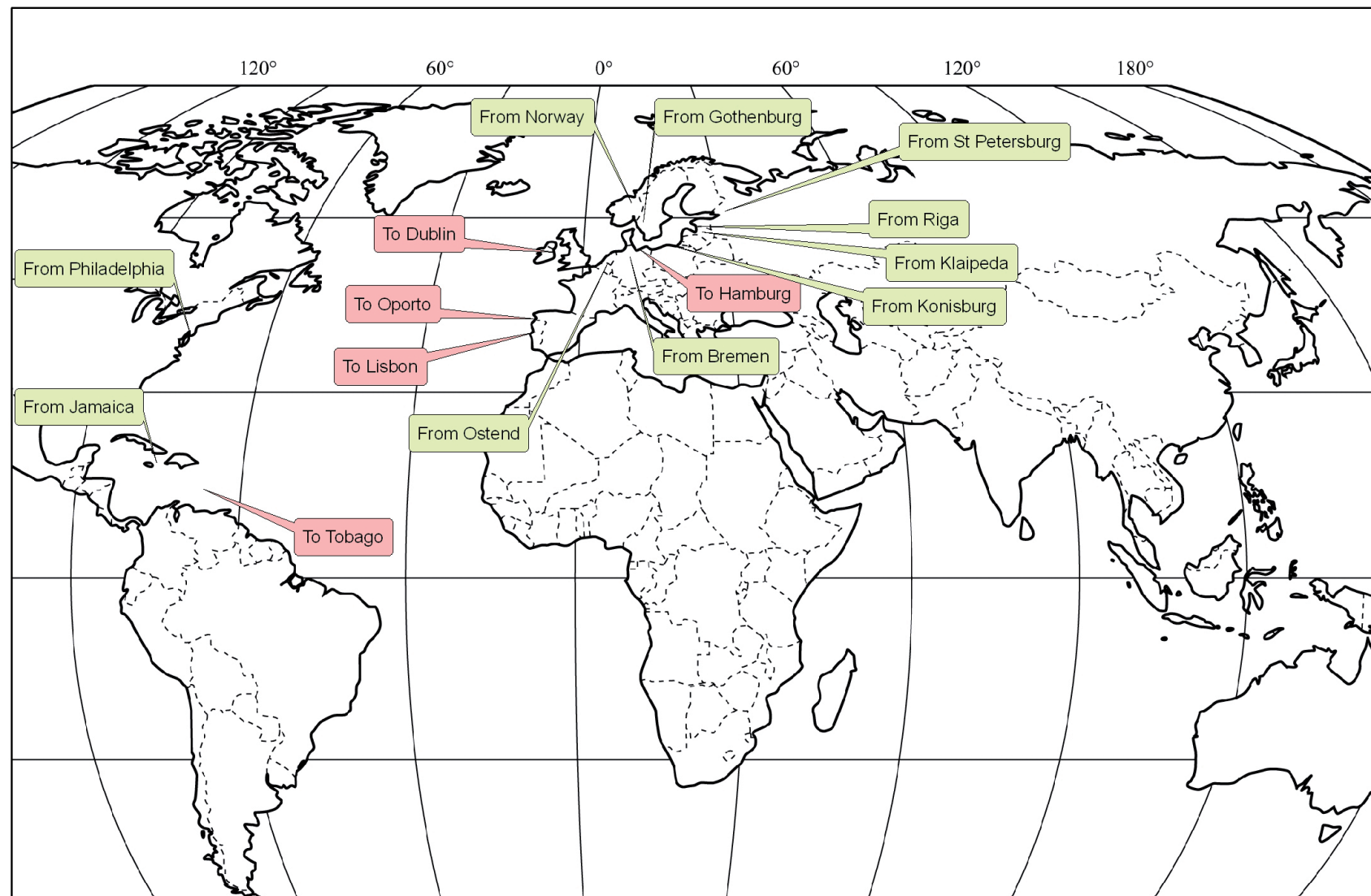


Figure 5.3.2: 18th century ports (to and from) from NMR/Shipwreck Index of the British Isles.

ingots, also with W Blackett stamped on them, have been reported to the Receiver of Wreck in the study area (Driot Number 021/06), perhaps lost at the beginning of their journey rather than the end, as with the Indian wreck.

As well as trade, fishing comprised an important component of the maritime character of the study area in the post-medieval, with the area part of the fishing grounds in this period. An act passed in 1716 banned the use of trawling as a method of fishing, though this was repealed by the *Sea Fisheries Act* of 1868. It was the arrival of the Hull to Selby Railway in 1840 which allowed the fishermen

to distribute their catches to a wider market. The discovery of the fish stocks in the Great Silver Pit helped develop this local industry into one of national importance during the 19th century (<http://www.hulltrawler.net/>).

The vessels used for fishing were collectively termed smacks, with the early vessels lug-rigged, progressing to cutter, sloops, and ketch rigged vessels. While an important part of the local economy in general, they were an unwelcome addition to the people of Hull. The merchants begrudged them the space in the busy docks as they increased congestion and crowded the

dock side and the increase in population brought with it problems such as overcrowding and disease. The fishermen were actively encouraged to move to Grimsby, which was closer to the mouth of the Humber and thence the fishing grounds and which offered better berthing and landing facilities at cheaper rates. This would ultimately lead to Grimsby becoming one of the largest fishing ports in the country (<http://www.hulltrawler.net/>).

It is not only through trade, communication, fishing and military affairs that the sea influenced in Britain. The seaside resort, first 'invented' in the 18th century as a form of medical treatment, came into its own during the Victorian period with the expansion of large-scale resorts offering holidays to the growing population of clerks, shopkeepers and the industrial working class. Skegness was one such Victorian holiday resort, offering simple amusements (<http://skegnessvideo.com/2008/09/revisit-skegness/>). Skegness pier, built in 1881 from cast iron with a Jarrah-wood deck, was the epitome of Victorian architecture. Its success was due to its association with passenger steamers, with day excursions across the Wash to Hunstanton being the most popular day trips (<http://www.theheritagetrail.co.uk/piers/skegness%20pier.htm>). The Shannon, lost in a gale in 1893 with a tragic loss of 27 lives, was possibly on one of these.

WWI

During the First World War, the area saw much activity. Trade and fishing continued to be important, though now it became imperative to protect such industries against the threat of submarine attack and mines.

It has been suggested that the Admiralty ignored the defences of the east coast during this period, the 5 anchored guard ships set to defend against a German landing in the Humber River were old and potentially had little fighting value (<http://www.gwpda.org/naval/fdrn0003.htm>).

By 1914, both Britain and Germany had sufficiently developed submarine technology to form squadrons for offensive purposes (Keegan 1988, 113). At the start of the war, the HMS *Bonaventure* was deposited in the Humber as part of the 6th Flotilla (<http://www.gwpda.org/naval/rnss4814.htm>).

In addition, contact mines, developed during the Crimean War, were in use by all advanced navies. These mines detonated when struck by a ship, and were moored to the sea-bed by a cable that held them just below the surface of the water (Keegan 1988, 113).

The eventual response to the threat of submarines came in 1917, when convoys of merchant ships sailed under the protection of destroyers and other naval armed escorts. During April of that year, the success of the unrestricted U-boat action was huge, with one in four ships sailing from Britain being sunk. Sailing in convoy meant the merchant ships were unable to sail at the best economic time, and could only move as fast as the slowest ship in the group, and initially there was opposition to the practice. However, the results spoke for themselves, and the number of ships sunk by U-boats was substantially reduced (O'Hara, 2010: 144; (<http://www.britannica.com/EBchecked/topic/648646/World-War-I/53157/Naval-operations-1917>).

The area was attacked both by sea and by air during this period. The main phase of Zeppelin raids occurred during the spring and summer of 1915, with a raid on Hull on 6 June leading to street riots (Dobinson 2001, 27).

WWII

At the start of WWII Britain had the largest navy in the world, including 12 battleships, 3 battle cruisers, 15 heavy and 45 light cruisers along with 184 destroyers, 58 submarines and 27 motor torpedo boats (World War II handbook 2004). The Coastal Command of the RAF had 171 aircraft the day war broke out (HMSO 1942).

Coastal command was formed in 1919 and in 1937 the administration of the Fleet Air Arm was placed under the jurisdiction of the Admiralty with the principle task of providing trained shore-based squadrons for the defence of trade and the co-operation with the Royal Navy in home waters (HMSO 1942).

It was vital that trade continued, and as such, learning from the experience of WWI, the Admiralty instituted a convoy system immediately. A booklet, Coastal Command, first published in 1942, suggests that Germany began to sink any ship in sight carrying cargo to Britain and stating that an average of 85 ships were escorted daily throughout November 1939 (HMSO 1942).

The threat to shipping was both from below the sea and from the air. Initially, one of the most effective weapons used against

shipping were magnetic mines, dropped from the air, which sunk to the seabed and then rose to attach onto passing ships. They were far superior to the mines laid by Britain to defend the shipping. However, this threat was overcome by the 'capture' and reverse engineering of one of these mines, and their subsequent 'de-gaussing' with electric cables to neutralise the magnetism (WWII handbook 2004). The mines were exploded by low flying aircraft, though ships were also adapted to counter the threat (see below).

German U-boats also posed a serious threat to shipping. The early adoption of a convoy system by the allies led to the German counter measures of U-boats operating in 'Wolf Packs' (O'Hara 2010, 154). These were spread out lines of U-boats, which would be in contact with each other. Once a U-boat had spotted a convoy, it would follow without engaging, until others in the pack were also present. It was accepted procedure to surface after dark and attack (WWII handbook 2004). This threat was countered when Britain finally cracked the German radio code signals, including HF/DF (huff duff), which triangulated the signals from the submarines and allowed the Allies to identify the U-boats location. Convoys could then circumnavigate around the lines of U-boats. Most of this was happening in the Atlantic, though there are several instances of U-boat attacks within the study area (see below).

The German arsenal also included E-boats, or *schnellboots* (fast craft), a type of German torpedo boat, designed for operations in the North Sea, English Channel and Baltic Sea. For a period in WWII, they controlled a large portion of the Mediterranean Sea and a sizeable area of the English Channel, specifically the area between Smiths Knoll and The Wash called E-boat Alley. Any boats travelling the eastern coastal route between London and the north were at risk from these craft. (<http://www.military.com/features/0,15240,78723,00.html>).

Once France had been occupied and the airfields of the Low Countries and Norway had also been taken over by the Germans, Britain was in reach of the Luftwaffe, who outnumbered the RAF at the time by a ratio of 3 to 1. *Operation Sealion*, the invasion of Britain, was set for September 1940, with the intention of totally destroying the RAF and confining the Royal Navy to the North Sea first (Alexander 1998). The Battle of Britain was conducted in 3 stages. Phase 1 saw the attacking of the lifeline convoys, Phase 2 was targeted at the RAF bases and Phase 3 comprised the bombing of the cities.

For Phase 2, Britain had the most advanced radar system in the world, which gave early warning of impending attacks from the Luftwaffe. Fighter Command had enough time to get the aircraft of the RAF into the air before the arrival of the Luftwaffe and so the attacks were far less successful than the Germans were expecting.

On the 18th and 19th of June 1940 there was intensive overland activity, with 50 to 60 aircraft ranging widely across England bombing the Northumberland coast, the Humber area and airfields in Kent (Dobinson 2001, 196).

On the 15th of August 1940, 1800 sorties were flown by German aircraft attacking targets from Newcastle to Hampshire. The following day, another 1700 were flown (WWII handbook 2004).

While the attacks on the cities were predominantly aimed at London, many other cities were also attacked by the Luftwaffe, including Hull (Dobinson 2001, 267). The first bombs were dropped on Hull in June 1940 (Geraghty 1989). Over the course of the war, there were 82 raids on the city during which high explosive and incendiary bombs were dropped, with 815 alerts. During these raids over 1000 people were killed, with over 3000 injured, and over 86 000 houses were damaged (Geraghty 1989). There was an attempted 130 bomber raid on the city in April 1944, though none of the bombs hit the city (Dobinson 2001).

British, German and potentially American aircraft would have crashed into the North Sea in the study area. Though the coast along the area had many anti-aircraft batteries, including many at Hull, the effectiveness of these defences was highly limited. During 12 000 sorties over the course of the war, only 75 aircraft were actually brought down by anti-aircraft guns (WWII handbook 2004).

In addition to shipwrecks in the Second World War, the area would have been frequented by aircraft. German bombers would have flown over the area heading for the industrial heartland of England, attempts which would have potentially been thwarted by the numerous anti-aircraft batteries along the coast in this area, and by aircraft from the airforce bases in the area. These aircraft bases also saw the Royal Air Force (RAF) and the United States Army Air Force (USAAF) carry out bombing raids.

The archaeological remains on the coast, documented by the Defence of Britain project (<http://www.britarch.ac.uk/projects/dob/>,

Figure 5.3.1) highlights the threat and the extent of measures against the threat during this period.

5.3.4 Wreck Inventories — Documented and Charted within the REC Study Area

The NMR polygon dataset, which allocates entries to named locations (Table 5.3.1 and Figure 5.3.3), as well as the NMR point dataset, and charted wrecks on the SeaZone/UKHO dataset that were sunk up to and during WWII were assessed as a whole, in order to highlight the history and potential for wrecks within the wider study area. Due to the volume of numbers, this assessment focuses on wrecks recorded at named locations offshore and, while some named locations on the coast, or within the mouth of the Humber are also used, these do not include the 19th century wreck data as it was felt that there were sufficient numbers of wrecks of this date within the Study Area itself to characterise the archaeology of this period. The data is generated from the original datasets and additional information in the *Shipwreck Index of the British Isles* (Larn and Larn 1997).

As this data is from documentary sources of varying quality and quantity, potential bias in the data needs to be acknowledged, as it is unlikely that this data represents an even and accurate list of all wrecks in the area. It is possible despite this to determine broad trends, especially in the later 18th century onwards, as the data is mostly derived from Lloyds List, and is therefore more consistent and comparable.

Analysis of the offshore named locations shows that the earliest wrecks documented within the area are from the 13th and 14th centuries, while the vast majority of wrecks date from the 19th century (Table 5.3.2). Where the causes of wrecking are documented, they are varied, though storms and gales, stranding, collisions and enemy attack are the most common (Table 5.3.3).

From the 13th century up to the 18th century the wrecks are wooden sailing vessels of a variety of types. The 19th century witnesses the development of iron as a construction material, and steam as a propulsion method. There is one steel ship dated to the 19th century, though after this date, more and more ships are constructed from this material, with the majority of ships in WWII being of steel build (Table 5.3.4).

The cargoes transported to and from their destinations are of a wide variety. Hemp and wheat are documented in the 14th century, and the importance and dominance of the coal transport industry is well illustrated from the 17th century onwards (Table 5.3.5).

Fishing, especially trawling, is also an important industry reflected in the wrecks in the area, and many ships during WWI and WWII were requisitioned by the Admiralty for serving in a variety of duties. The huge range of destinations to and from local, national and international ports highlights the importance of the ports to the west of the study area within a global arena. London and the Newcastle area are dominant as ports, again associated with the transportation of coal, though the importance and expansion of international trade is also illustrated (Figures 5.3.2 and 5.3.4).

There are also 73 aircraft documented as lost within the study area (Table 5.3.6).

13th and 14th Century Wrecks

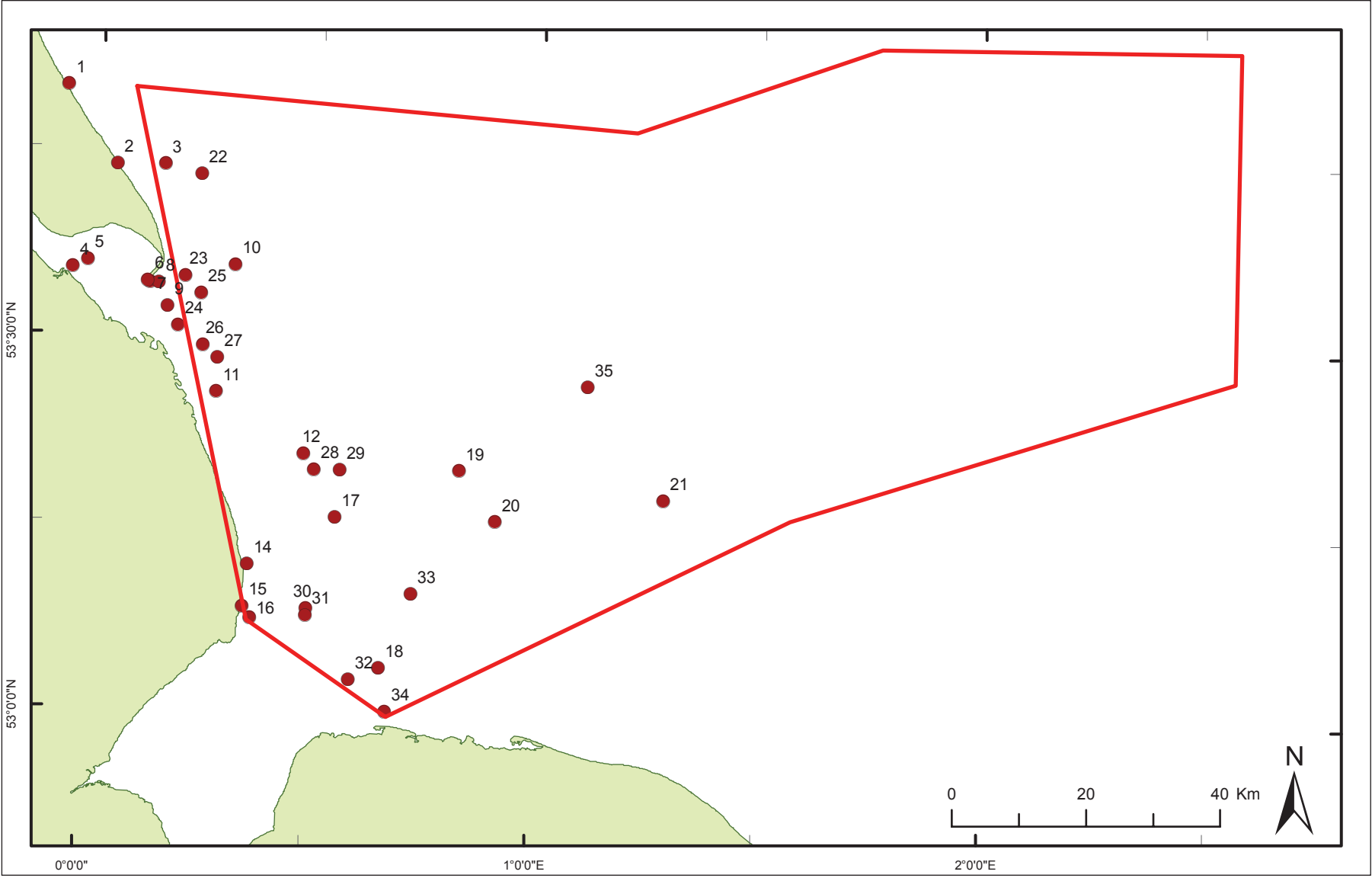
Ten wrecks potentially known in or in the vicinity of the study area are dated to the 13th and 14th centuries. The earliest is a wreck dated to 1255, The *Jacobus*, a German cargo vessel stranded in a storm in the Lindsey area (NMR 1446341). A second 13th century wreck is another cargo vessel, dated to 1269, though the NMR notes that although it was known to be wrecked near Emesdale (from the Calendar of Close Rolls 1268–1272), it has not been located (NMR 1446364).

The NMR holds 8 records relating to wrecks during the 14th century. NMR 1451022 records official records from the Calendar of Patent Rolls mentioning wrecks in Holderness dated to 1336 or earlier, and NMR 144726 was a cargo vessel apparently of Scottish origin, whose goods were claimed by Edward III as belonging to the Kings' enemies after the vessel stranded on the coast of Lincolnshire in 1353.

The Calendar of Patent Rolls also records the wrecking of a Flemish cargo vessel in 1373, which foundered somewhere between Yarm and Queenhithe in London (NMR 1451036). This was said to be carrying wheat and maliciously struck by another vessel, both of Seland. Again the location is approximate, and selected on the NMR as 'Lincolnshire Coastal Waters'.

Named_Location Number	Named Location
1	On the Holderness coast
2	Withernsea
3	10 Miles ENE of Spurn Head
4	Grimsby Inner Roads
5	Between Thorne and Louth
6	ESE of Spurn Head
7	Off Spurn Head
8	The Binks
9	NE Lincolnshire District
10	New Sand Hole
11	Off Saltfleet
12	Between Selby and London
14	On the coast of Lincolnshire
15	Skegness Beach
16	Skegness Middle Sane
17	Off the Inner Dowsing
18	Burnham Flats
19	Silver Pit
20	Near The Dudgeon Light Vessel
21	6 leagues NNW of Cromer
22	20 miles SE of Flamborough Head
23	Off the Outer Binks
24	Haile Sand Flat
25	Near New Sand Light Vessel
26	8 miles SE of Spurn Head
27	2.5 Miles NW of Donna Nook
28	3 miles ENE of the Inner Dowsing Shoal Light
29	Near Inner Dowsing Lightship
30	19 miles SE from Skegness
31	1.5 Miles NE of Skegness
32	Woolpack
33	12 miles south of Race Point
34	Off Thornham
35	Outer Dowsing

Table 5.3.1: NMR Named Locations.



Another ship was wrecked near Holderness while bound for Scotland with military equipment and provisions in 1386 (NMR 1450808), and in the same year, a German cargo vessel was stranded at the mouth of the Humber on her passage from Skane to Kingston-upon-Hull, laden with herring (NMR 1450796).

During a truce between England and Scotland in 1388, a Scottish ship was lost in a storm in the Lindsey area, though the NMR suggests that the references in the Calendar of Patent Rolls may be wrong, and the wreck may be located off the coast of Norfolk (NMR 1446366).

In 1391 a Prussian cargo vessel was wrecked off the coast of Lindsey. It appears that some of the mariners from Dansk (Gdansk) survived, and were awarded the goods from the wreck (NMR 1448320).

Another storm in 1392 was recorded as having wrecked the *Marie Knyght*, a cargo vessel laden at Dansk in Prussia, heading for England. This ship was wrecked off Withernsea, and it is recorded that all the sailors and crew survived (NMR 1449053).

Id	Total of OBJECTID	13 th century	14 th century	17 th century	18 th century	19 th century	20 th century pre War	1919–1938	WWI	WWII
0	577	2	5	6	74	310	32	5	38	51

Table 5.3.2: NMR listed wrecks by date.

Cause	Total of OBJECTID	13 th century	14 th century	17 th century	18 th century	19 th century	20 th century pre War	1919–1938	WWI	WWII
abandoned in bad weather	1					1				
attacked by aircraft	5									5
bombed	5									5
bulwarks washed away, hatch covering boards split	1					1				
burnt and foundered	2					2				
collision	84				4	63	11	3	3	
driven ashore	16				8	8				
explosion	4					2				2
foundered	85				14	55	9		4	3
gross carelessness of master, not secured cargo	1					1				
grounded	7				1	6				
Inability of pilot	1					1				
lost	1					1				
maliciously rammed	1		1							
mine	41								14	27
missing	3					2		1		
privateer	2				1	1				
privateers	1					1				
ran ashore	1					1				
run down	3					2	1			
shifted cargo	1					1				
skuttled by submarine	4								4	
sprung a leak	15				2	13				
storm/gale	79	1	1		6	69	2			
stranded	65	1	1	3	14	36	6	1	3	
Struck on Rose Sand	1					1				
struck submerged wreck	3					1	1			1
submarine	6								5	1
torpedo E-boat	5									5
weather, and want of seamanship and sobriety	1					1				

Table 5.3.3: Causes of wrecking listed in the NMR.

17th Century Wrecks

The NMR records no wrecks during the 15th and 16th centuries.

The wrecks dated to the preceding centuries are indicative of the international trade in the area, generated by Hull being a subsidiary of Kontore, a foreign trading post of the Hanseatic League.

Flemish, German, Prussian and Scottish ships are all recorded as having been lost in the area, carrying goods to and from Gdansk, Skane, etc. The goods are commonly described as wheat and 'divers goods'. Hull was also involved in the war between England and Scotland and was an important city exporting wool. The decline in wrecks recorded after this date may relate to economic decline in a wider European sense, though it may also reflect gaps in knowledge and recording on the NMR, as the Hanseatic league were still dominant in the 15th centuries.

10 wrecks recorded on the NMR date to the mid-17th century. NMR 1443028 records a wrecking in 1665, suggesting that ships in Hull harbour suffered much damage during a storm, and at Grimsby Road a vessel was lost, that was bound for Lynn (Kings Lynn). A coal ship is also thought to have been lost.

A Flemish Hoy is recorded as stranded on the coast of Lincolnshire in 1666 (NMR 1383294) and in 1667 the NMR records that a Hull vessel of 180 tons and a collier were driven into the Humber. The Hull vessel escaped and though the collier was wrecked, the men were saved (NMR 1386616). It is also recorded that this vessels cargo was coal, though the NMR further notes that cross-referencing suggests that this can not be ascertained. The same NMR entry notes that some vessels arrived from Yarmouth, and saw eight great wrecks at sea.

In 1668, 4 ships are recorded as being lost in the mouth of the Humber, with another possibly lost at the same time. Three of these are recorded as one entry on the *Shipwreck Index of the British Isles* (Larn and Larn 1997) and are described as light vessels bound for Newcastle (NMR 1392388 and NMR 1392390), two of which are broken in pieces, with the third much feared for. The other two recorded losses of this year were a large London collier, wrecked on the Bull Sand with a loss of 13 out of 17 men (NMR 1391630) and a small pink that sunk on the Stone Banks with a loss of all men (NMR 1391631).

Three ships are recorded as lost in 1669, given three separate

Ship_Type	Total of OBJECTID	13 th century	14 th century	17 th century	18 th century	19 th century	20 th century pre War	1919–1938	WWI	WWII
barge	1					1				
barque	5					5				
billyboy	2					2				
brig	36					36				
brigantine	3					3				
cargo vessel	4					4				
cutter	3					3				
dandy	16					16				
fishing drifter	3						1		2	
Galliot	1					1				
iron barque	1					1				
iron ketch	1					1				
iron steam ship	24					14	5		4	1
iron steam trawler	1						1			
iron trawler	2								2	
ketch	19					19				
lightship	2					1	1			
lugger	1					1				
motorised barge	1						1			
passenger vessel	1					1				
pilot cutter (sail)	1						1			
schooner	33					33				
schooner or barque	1					1				
ship	1					1				
sloop	18					18				
sloop or brigantine	1				1					
smack	7					7				
snow	2					2				
steam ship	2					2				
steel barge	1									1
steel fishing drifter	1									1
steel landing craft	1									1

Ship_Type	Total of OBJECTID	13 th century	14 th century	17 th century	18 th century	19 th century	20 th century pre War	1919–1938	WWI	WWII
steel motor vessel	1									1
steel motor vessel	2									2
steel steam ship	58					1	3	3	17	34
steel tanker	3									3
steel trawler	7						1	2	1	3
steel trawler armed	2									2
trawler	3					1			2	
tug	2					2				
wooden barque	2						1		1	
wooden brig	5				2	2	1			
wooden brigantine	2					1	1			
wooden cargo vessel	44	2	5	2	22	13				
wooden coaster	1				1					
wooden dandy	2						2			
wooden fishing vessel	1								1	
wooden hoy	2			1		1				
wooden keel	1					1				
wooden ketch	4						3		1	
wooden lugger	3					1	2			
wooden sailing vessel	143			3	37	101			2	
wooden sailling vessel	1				1					
wooden schooner	6						4		2	
wooden sloop	3				1	2				
wooden smack	2					1	1			
wooden steam ship	2					2				
wooden steam vessel	1						1			
wooden trawler	1								1	
wooden vessel	2				1	1				

Table 5.3.4: NMR listed types of ship filtered by date.

Cargo/purpose	Total of OBJECTID	13 th century	14 th century	17 th century	18 th century	19 th century	20 th century pre War	1919–1938	WWI	WWII
21 tons firebricks	1					1				
82 tons coal										
at moorings	2					1	1			
ballast	34				1	14	5		3	11
barge	1									1
bark	1					1				
barley	3					3				
bricks and tiles	1					1				
cement	5					3	1			1
chalk	3					2	1			
cheese	1				1					
china clay	2					1	1			
china clay, stone cut blocks	1					1				
coal	43				14	28	1			
coal cement, fire bricks	1					1				
coal coke unspec	1						1			
coal unspec	74				4	42	4	3	11	10
coal, patent fuel	1					1				
coal, stone	1					1				
copper ingots, tin ingots, ammunition, other	1									1
copper ore	1						1			
corn	2				1	1				
cotton, seed	1					1				
creosote	1									1
fertiliser	1									1
fireclay bricks	1					1				
fishing	46				1	25	7	2	8	3
flax	1					1				
furniture, passengers	1					1				
general cargo	9				2	2			2	3
general cargo and wine	1					1				
general cargo, copper, steel	1									1
general gargo, government stores	1									1
Government munition stores	1						1			
groceries	1					1				
gunpowder rum	1					1				

Cargo/ purpose	Total of OBJECTID	13 th century	14 th century	17 th century	18 th century	19 th century	20 th century pre War	1919–1938	WWI	WWII
hemp	1					1				
herring	1		1							
iron	2					2				
iron and deals	2				2					
iron ore	4						1		1	2
iron, cast ingots	1								1	
iron, cast ingots and pigs	1					1				
iron, ore	1								1	
iron, scrap	2					2				
maize	1					1				
navy	12								3	9
oak	1					1				
oil	1					1				
oil, cake	1					1				
ore burnt	1						1			
palm, oil	1									1
passengers	2				1	1				
phosphate unspec Esparto grass	1					1				
pit props	1						1			
pleasure cruising	1					1				
potatos	1					1				
railway track	1						1			
rape seed	1					1				
rye and copper unspec	1				1					
salt	1					1				
salt iron unspec	1					1				
sand unspec	3					1			2	
seeking and return	1						1			
shingles (roofing)	1					1				
slate stone	1					1				
soda	1					1				
tiles (floor/ roofing)	2					2				
tobacco	1					1				
towing	1					1				
wheat	7		1			6				
wheat seed unspec	1					1				
whelking	1					1				
wine unspec	1					1				
wood	4					3			1	

Table 5.3.5: NMR listed wreck cargoes.

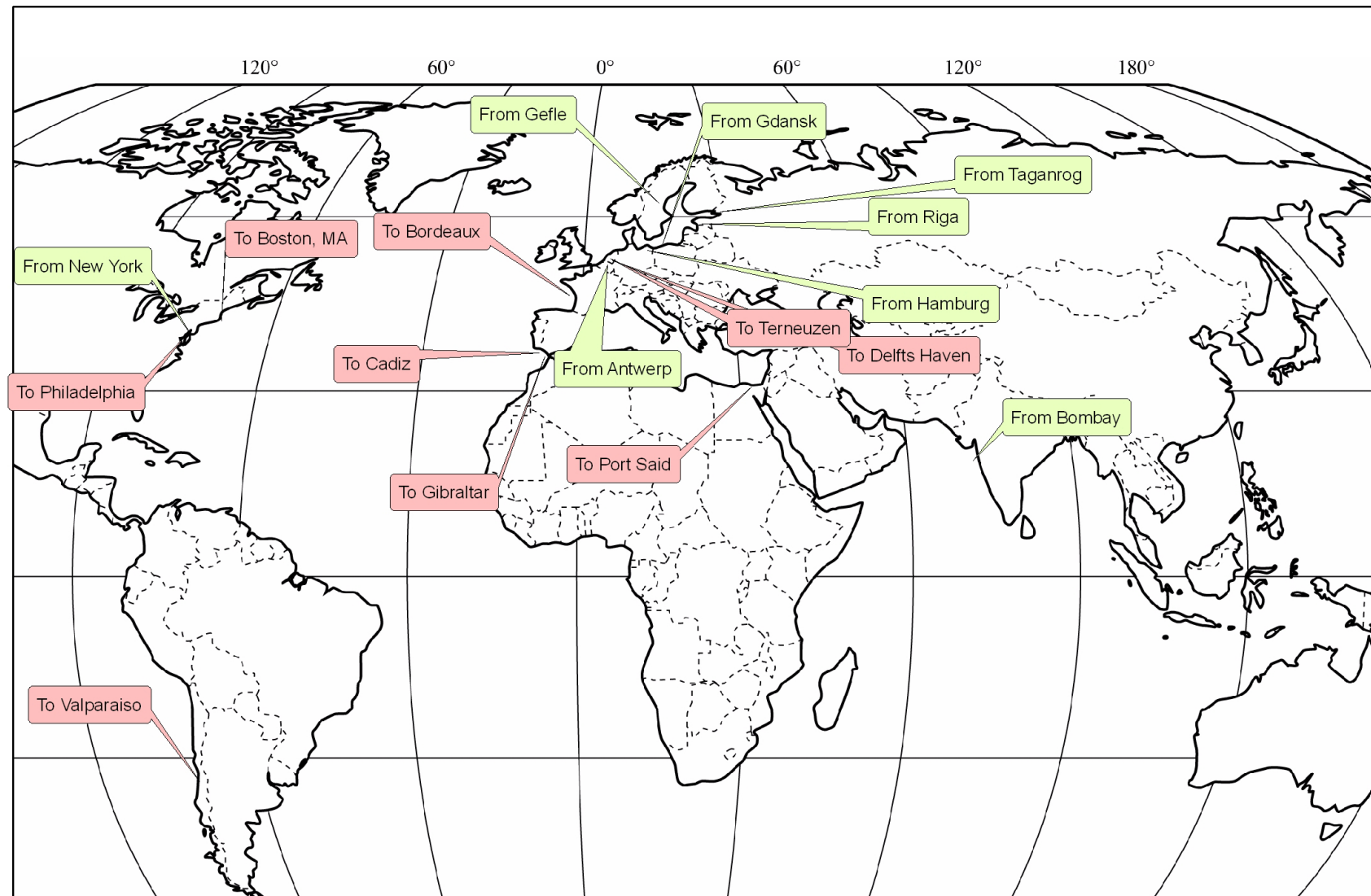


Figure 5.3.4: Selected ports (to and from) in the 19th century (NMR dataset).

numbers on the NMR (NMR 1392394, NMR 1392399 and NMR 1392400), though these are from one source, (Larn and Larn 1997 and CSP Dom Charles II).

It is interesting to note that there are no other entries for the 17th century for the area than those of these 4 years. The original source for information regarding these wrecks is the Calendar of State Papers Domestic (CSP), cited by the *Shipwreck Index of the British Isles* (SIBI), and subsequently incorporated into the NMR. It is possible that wrecking incidents were only recorded for these dates on the CSP, however, it is also possible that the SIBI

selected only these years to search. The CSP 1675 in May and June mentions the new lighthouses and in particular their effect in increasing the safety of navigation in and out of the Humber around Spurn Head, though a search of this dataset online (British History online) identified no new wrecks either side of this date. It is not likely that the wrecks of these years are the only wrecks in the area during this century. It is more likely that these years are representative of other years during the 17th century and as such, substantially more wrecks may potentially be present within the area than are presently recorded on the NMR.

18th Century Wrecks

The wrecking incidents of the 18th century on the NMR are mostly documented from three sources. The Great Gale of 1703 claimed a substantial number of ships throughout the whole of England and North Sea area, including 12 reported in the Humber region. These are noted from contemporary sources, comprising Daniel Defoe's collection of first hand accounts (Defoe 1703 *The Storm*) and reports in *The Daily Courant*, London's first daily newspaper which had recently been established in 1702. Wrecks recorded in 1737, 1738 and 1740 were also derived from contemporary newspapers such as *The Newcastle Courant* and *The Sherbourne Mercury*. The entries from the early newspapers were added by the NMR around 2003 in an attempt to fill in the gaps in the Maritime Record for the early 18th century (http://www.english-heritage.org.uk/upload/pdf/dsu_march03.pdf).

From 1740 extant issues of Lloyds List exist and much of the wreck data for the rest of the 18th century and later comes from this source, published and enhanced by *The Shipwreck Index of the British Isles* (Larn and Larn 1997).

128 wrecks are documented on the NMR dated to the 18th century. The earliest is from 1701, when in February of that year, John Thompson of Stockton, with the whole of his ship's company, except one man, were 'cast away' on the coast of Lincolnshire (NMR 1461558) (<http://www.angelfire.com/de/BobSanders/NESHIPPING.html>).

Contemporary accounts of the Great Gale, such as those collated by Defoe and reported in *The Daily Courant*, reflect the exceptional devastation and confusion created by this storm. Lamb (1991, 59) cites Short (1749) who reported that 'England lost more ships in this storm than ever were lost in any encounter with an enemy'. Estimates of lives lost range from 1500 to 10 000 in total, with buildings being blown down in southern England and across the continent (Lamb 1991, 59).

The storm was not quite as severe in the Humber region as it was further to the south, but it still caused substantial damage and the NMR records at least 12 ships lost in the area, a number very likely to be underestimated due to the difficulty in identifying and listing individual losses, both at the time and from later research. The majority of the ships recorded on the NMR were colliers, travelling to and from Newcastle.

Aircraft	year date	NMR ID	NAME	DESCRIPTION	FLAG	Named_ Loc
Aircraft	1939	1328998	WELLINGTON MK IA N2983	BRITISH BOMBER, 1939	British	43
Aircraft	1939	1399685	HEINKEL HE 1115B S4+EH	1939 wreck of a German Heinkel He 111 bomber which was shot down 5 miles east of Spurn Head. It was part of the coast flying corps.	German	42
Aircraft	1940	1318608	HAMPDEN MK I P1354	BRITISH BOMBER, 1940	British	4
Aircraft	1940	1321029	HAMPDEN MK I P4351	BRITISH BOMBER, 1940	British	30
Aircraft	1940	1321076	HAMPDEN MK I P4380	BRITISH BOMBER, 1940	British	9
Aircraft	1940	1323066	BLLENHEIM MK IV R3765	BRITISH BOMBER, 1940	British	19
Aircraft	1940	1325173	SPITFIRE MK I L1051	BRITISH FIGHTER, 1940	British	20
Aircraft	1940	1327572	HAMPDEN MK I L4065	BRITISH BOMBER, 1940	British	30
Aircraft	1940	1327607	HAMPDEN MK I L4093	BRITISH BOMBER, 1940	British	7
Aircraft	1940	1327771	BATTLE MK I L5027	BRITISH BOMBER, 1940	British	27
Aircraft	1940	1354033	HAMPDEN MK I X2897	BRITISH BOMBER, 1940	British	30
Aircraft	1940	1354043	HAMPDEN MK I X3027	BRITISH BOMBER, 1940	British	30
Aircraft	1940	1354297	BLLENHEIM MK IV Z5754	BRITISH LIGHT BOMBER, 1940	British	34
Aircraft	1940	1393564	HE111 5J+BL	1940 wreck of German Heinkel bomber which was shot down 15 miles off the River Humber <i>en route</i> to Birmingham.	German	9
Aircraft	1940	1393567	HE111 5J+EL	1940 wreck of German Heinkel bomber which was shot down off the Humber on a sortie to Kingston-upon-Hull.	German	9
Aircraft	1940	1400253	DORNIER DO17Z-E	1940 wreck of a German Dornier Do17 which was shot down off Skegness. It was part of Squadron KG3.	German	30
Aircraft	1940	1400259	DORNIER DO17Z-3	1940 wreck of a German Dornier Do17Z-3 which was shot down off Scolt Head. It was part of Squadron 4/KG3.	German	34
Aircraft	1940	1401347	HEINKEL HE111H-5 (3554) A1+CH	1940 wreck of a German Heinkel He111 reconnaissance aircraft which ditched off Chapel St. Leonards following gun action. It was part of Squadron 1/KG53.	German	13
Aircraft	1941	1319291	HURRICANE MK I P3210	BRITISH FIGHTER, 1941	British	27
Aircraft	1941	1322717	WELLINGTON MK IC R1271	BRITISH BOMBER, 1941	British	12
Aircraft	1941	1322724	WELLINGTON MK IC R1288	BRITISH BOMBER, 1941	British	7
Aircraft	1941	1322963	WELLINGTON MK IC R3169	BRITISH BOMBER, 1941	British	7
Aircraft	1941	1354038	HAMPDEN MK I X3021	BRITISH BOMBER, 1941	British	19
Aircraft	1941	1354050	HAMPDEN MK I X3062	BRITISH BOMBER, 1941	British	37
Aircraft	1941	1354263	HURRICANE MK IIB Z3670	BRITISH FIGHTER, 1941	British	23
Aircraft	1941	1354370	WHITLEY MK V Z6802	BRITISH HEAVY BOMBER, 1941	British	3
Aircraft	1941	1354560	WHITLEY MK V Z9204	BRITISH HEAVY BOMBER, 1941	British	18
Aircraft	1941	1354561	WHITLEY MK V Z9211	BRITISH HEAVY BOMBER, 1941	British	4
Aircraft	1941	1357388	SPITFIRE MK I X4594	BRITISH FIGHTER, 1941	British	30
Aircraft	1941	1357392	WELLINGTON MK IC X9811	BRITISH HEAVY BOMBER, 1941	British	7
Aircraft	1941	1357711	HURRICANE MK I V7606	BRITISH FIGHTER, 1941	British	15
Aircraft	1941	1401883	JUNKERS JU88A-5 (0404) F6+BM	1941 wreck of a German Junkers Ju88 which was shot down and crashed off Skegness. It was part of Squadron 4(F)/122.	German	15
Aircraft	1941	1401897	DORNIER DO17Z-2 (4248) U5+DA	1941 wreck of a German Dornier Do17 which was shot down and crashed south east of Skegness Pier. It was part of Stab KG2.	German	15
Aircraft	1941	1402776	JUNKERS JU88A-5 (6263) V4+GP	1941 wreck of a German Junkers Ju88 which was shot down and crashed off Spurn Head. It was part of Squadron 6/KG1.	German	6
Aircraft	1941	1402812	HEINKEL HE111H-5 (3956) 5J+ES	1941 wreck of a German Heinkel He111 which crashed in the sea off Kingston upon Hull. It was part of Squadron 8/ KG4.	German	9

Table 5.3.6: Aircraft loss locations listed in the NMR.

Aircraft	year date	NMR ID	NAME	DESCRIPTION	FLAG	Named_ Loc
Aircraft	1942	1318526	HAMPDEN MK I P1161	BRITISH BOMBER, 1942	British	11
Aircraft	1942	1323080	BLLENHEIM MK IV R3838	BRITISH BOMBER, 1942	British	12
Aircraft	1942	1329937	HAMPDEN MK I N9070	BRITISH BOMBER, 1942	British	11
Aircraft	1942	1342848	WELLINGTON MK III BJ595	BRITISH BOMBER, 1942	British	24
Aircraft	1942	1354135	SPITFIRE MK I X4353	BRITISH FIGHTER, 1942	British	17
Aircraft	1942	1354168	WELLINGTON MK IC Z1145	BRITISH HEAVY BOMBER, 1942	British	7
Aircraft	1942	1354212	WELLINGTON MK IV Z1285	BRITISH HEAVY BOMBER, 1942	British	19
Aircraft	1942	1354383	WHITLEY MK VII Z6960	A British Armstrong Whitworth Whitely, which crashed in 1942: the crash was due to mechanical failure.	British	19
Aircraft	1942	1354500	WELLINGTON MK II Z8537	BRITISH HEAVY BOMBER, 1942	British	7
Aircraft	1942	1357289	HALIFAX MK II W1225	BRITISH HEAVY BOMBER, 1942	British	5
Aircraft	1942	1404676	JUNKERS JU88D-1 (1342) 8H+KL	1942 wreck of a German Junkers Ju88 which was shot down and crashed 20 miles north of Cromer. It was part of Squadron 3(F)/33.	German	21
Aircraft	1943	1343364	BOSTON MK IIIA BZ376	BRITISH BOMBER, 1943	British	30
Aircraft	1943	1352850	LYSANDER MKIIIA V9797	BRITISH ARMY COOPERATION, 1943	British	30
Aircraft	1943	1354724	HALIFAX MK V LL120	BRITISH HEAVY BOMBER, 1943	British	30
Aircraft	1943	1354846	BEAUFIGHTER MK X LX826	BRITISH FIGHTER, 1943	British	9
Aircraft	1943	1355191	HALIFAX MK II HR924	BRITISH HEAVY BOMBER, 1943	British	9
Aircraft	1943	1356378	LANCASTER MK III JB229	BRITISH HEAVY BOMBER, 1943	British	13
Aircraft	1943	1356748	LANCASTER MK I ED392	BRITISH HEAVY BOMBER, 1943	British	6
Aircraft	1943	1404778	DORNIER DO217K-1 (4412) U5+BA	1943 wreck of a German Dornier Do217 which was shot down and crashed 15 miles east of Spurn Head. It was part of Stab/KG2.	German	19
Aircraft	1943	1404780	DORNIER DO217M-1 (6045) U5+GK	1943 wreck of a German Dornier Do217 which was shot down and crashed off Spurn Head. It was part of Squadron 2/KG2.	German	19
Aircraft	1943	1404789	DORNIER DO217E-4 (4329) U5+KN	1943 wreck of a German Dornier Do217 which was shot down and crashed off the Lincolnshire coast. It was part of Squadron 5/KG2.	German	12
Aircraft	1943	1404791	JUNKERS JU188E-1 (260175) Z6+GK	1943 wreck of a German Junkers Ju188 which crashed near Spurn lighthouse. It was part of Squadron 2/KG66.	German	6
Aircraft	1944	1317710	MOSQUITO MK II DD629	BRITISH FIGHTER, 1944	British	18
Aircraft	1944	1340427	LANCASTER MK III PB294	BRITISH BOMBER, 1944	British	12
Aircraft	1944	1340440	LANCASTER MK III PB702	BRITISH BOMBER, 1944	British	30
Aircraft	1944	1340797	LANCASTER MK I ME788	BRITISH BOMBER, 1944	British	30
Aircraft	1944	1355031	WELLINGTON MK X HE915	BRITISH BOMBER, 1944	British	2
Aircraft	1944	1356564	BEAUFIGHTER MK X NE577	BRITISH FIGHTER, 1944	British	9
Aircraft	1944	1356580	BEAUFIGHTER MK X NE760	BRITISH FIGHTER, 1944	British	21
Aircraft	1944	1356835	STIRLING MK III EE914	BRITISH HEAVY BOMBER, 1944	British	30
Aircraft	1944	1356842	STIRLING MK III EF246	BRITISH HEAVY BOMBER, 1944	British	5
Aircraft	1944	1404890	HEINKEL HE177A-3 (2375) 6N+OK	1944 wreck of a German Heinkel He177 which was shot down and crashed off Skegness. It was part of Squadron 2/KG100.	German	30
Aircraft	1945	1340787	LANCASTER MK III ME 357	BRITISH BOMBER, 1945	British	30
Aircraft	1945	1354740	WELLINGTON MK X LN653	BRITISH BOMBER, 1945	British	12
Aircraft	1945	1356555	LANCASTER MK III ND861	BRITISH HEAVY BOMBER, 1945	British	5
Aircraft	1945	1356558	LANCASTER MK III ND869	BRITISH HEAVY BOMBER, 1945	British	30
Aircraft	1945	1357534	LANCASTER MK I LL952	BRITISH HEAVY BOMBER, 1945	British	26

In 1737 the *Lady Gossina*, travelling from Bremen to London, was stranded near the mouth of the Humber, though contemporary accounts note that most of the rich cargo was saved (NMR 1375579). In 1738 an English sloop or brigantine foundered following a collision while fishing off Withernsea and Owthorne. The NMR notes that the incident appeared to be exaggerated, as the information gained was from the trial of John Longden, the master of the second ship involved in the incident reported in local newspapers. He was accused of covering up the incident by murdering the survivors, though he was later honourably acquitted (NMR 1458790). *The Newcastle Courant* reported in 1740 that 10 men were saved from the *Britannia* which foundered during a storm whilst sailing from London to Kingston-upon-Hull. The actual location of loss is not mentioned (NMR 1376407).

From 1741 records are available from Lloyds List, and consequently both the quality and the quantity of data increases. These lists still, however, are unlikely to be a full record of all losses. The NMR supplements, cross references and enhances these lists with information from contemporary newspapers and journals and additional information has been gained from *The Shipwreck Index of the British Isles* (Larn and Larn 1997).

Almost all the ships listed were of English or British flag, with only a few Dutch and French ships listed as lost in the area. Substantial numbers were identified as *en route* from English ports such as Newcastle, Kings Lynn, London, and Hull, with similar destinations. For the destinations, the proportions were substantially different, with the majority of ships voyaging to London. International voyages are well represented in the record, with places such as Philadelphia, Tobago and Jamaica listed. Seven ships voyaging from St Petersburg are listed on the NMR/Shipwreck Index, 5 destined for London, with one *en route* to Hull and one *en route* to Dublin. Other ports around the Baltic Sea are also listed.

Where the cargo is known of these ships, 25 were carrying coal and of these, almost all were from Newcastle and predominantly *en route* to London. Iron, timber, lead and flax are all represented as cargo, as well as other commodities such as foodstuffs. In the 1760s three ships carrying corn from Kings Lynn were lost, and in 1769 the *Field*, a cargo vessel *en route* from Hull to London carrying cheese was lost (NMR 1376457). The entry for this incident includes references to *The Newcastle Courant* from

30th December 1769, and highlights the risk merchants took transporting goods by sea.

'York, Dec 26...The principal part of the cargo, which was very considerable, belonged to the cheesemongers in London. But amongst the sufferers in York by this loss, is one whose case is truly pitiable; and we beg leave to make his misfortunes known, not doubting but the charitable and well-disposed part of our readers will contribute to his relief. The person for whom we would solicit these donations, is Thomas Kirby of Thursday M---, who a few years ago lost his all by the death of this partner, who was insolvent...His lost by this ship has once more brought him to absolute poverty..' (NMR 1376457).

Three passenger ships were also recorded as wrecked during this century, including the *Betsy*, a Scottish passenger vessel which was stranded at Northcotes *en route* from Leith to London in 1767, with a loss of 27 lives (NMR 924756).

The vast majority of ships from this period are described in generic terms as wooden sailing vessels, or wooden cargo vessels. Where ship types are more specific, they include sloops and brigs, with a snow, a schooner, a coaster and a brigantine also listed.

The causes of wrecking are also varied. Weather undoubtedly played an important part, not only with storms, such as the Great Gale of 1703, but instances of fog, or an increase in tidal flow from the Humber due to rain, which also increased the risk of wrecking. One such incident claimed the *Grocer*, a passenger vessel stranded on the Trinity Sand in 1770. The incident was reported by *The Newcastle Courant*.

'Newcastle, Dec. 1... A correspondent just arrived from Yorkshire, informs us, that the rainy weather in those parts a fortnight past is astonishing... dreadful consequences are apprehended by the banks of the rivers breaking, and inundations all over the Flat from Ferrybridge to the Humber,

'Edinburgh, Dec. 15... A letter from Mr Edmonstone, who was one of the passengers saved out of the ship GROCER, lately lost, says that it is supposed that the sandbank at the mouth of the Humber, on which the ship struck, was thrown up by the rapidity of the stream and

the meeting of the tide, during the late great floods in that river..' (NMR 1386545).

Other casualties due to storms include three colliers, the *Jane*, the *Industry* and the *Dove*, which were lost *en route* from Newcastle to London in 1773 (NMR 1387088, NMR 1387089 and NMR 1387090). The *Hannah*, a cargo vessel *en route* from Shields to London with a cargo of coal, foundered after a gale in 1791 (NMR 1376690).

While weather, navigational hazards, accidents and un-seaworthy ships caused the majority of wrecking incidents, anthropogenic factors also played a small but important part in increasing the danger of maritime activity in the area. Privateering is mentioned in a few of the sources, the majority being letters and articles in *The Newcastle Courant*.

One such letter, from the *Hopewell*, of Harwich, dated Oct 13 (1779) says;

'I take the liberty to inform you how this coast is infested by the French privateers; we have seen 7 sail between here and Flamborough head, and have taken up, on a piece of a wreck, a man that has been cast away in one of them, who says, that they had just taken... a brig of 7 keels, from Newcastle for Margate' (NMR 1387448).

In 1781, the *Good Intent* foundered after being taken by a French privateer. Again, *The Newcastle Courant* covered the story, telling of how after the ship was taken by the privateers, the mate, with the men and boys, 'seized a proper opportunity and rose on the 8 Frenchmen and retook the ship'. Unfortunately soon after this the ship canted her ballast and was wrecked, with the people on board saved by a brig from Lynn (NMR 1387794). In 1783, the *Traveller*, *en route* from St Petersburg to London is recorded as having been driven on shore by a privateer (NMR 1302644).

An English privateer is recorded to have engaged and sunk a French snow off Spurn Head in 1779 (NMR 1387425).

The excitement, intrigue and interest in the privateers in the contemporary media, is illustrated in the record of the *Ann and Henry*, an English collier *en route* from London to Newcastle. From the NMR entries, citing the *Newcastle Courant* of 28th June 1777 (NMR 1387326);

‘a letter from Grimsby, in Lincolnshire, dated June 19, says, “Three American privateers of 18 guns, and full of men, yesterday appeared off Hornby, and fired on some colliers, bound from London to Newcastle-upon-Tyne. After a few shots on both sides, and the loss of three masts among the colliers, the wind being NE the colliers drove into the Humber, and got clear off, except the ANN AND HENRY, which was so much shattered, that she was forced to strike. One of the privateers sent a boat on board, and took away what articles they chose and all the people, among whom was a clergyman, and his wife, who lately fled from Boston in New England. They then sheered off towards Dunkirk, leaving the collier, which drove on Spurn Head during the night, and beat to pieces.”’

However, a week later, on the 5th of July 1777, *The Newcastle Courant* published a retraction of this story;

‘We are assured from good authority, that the account in the London papers of 3 American privateers, of 18 guns each, having appeared off Hornby, Lincolnshire, and fired on some Newcastle colliers, is void of foundation.”

19th Century Wrecks

From the 19th century onwards, in addition to documentary information regarding wrecks and wrecking incidents, there is physical evidence of wrecks on the seabed within the study area, collected and maintained by the UKHO. The proportion of wrecks positively identified on the seabed to those documented as lost is still relatively low. Over time, wrecks would be buried and vessels constructed from wood would deteriorate faster than those made of metal, factors which are likely to contribute to the discrepancy.

In the general study area, nine wrecks from the 19th century are identified as points on the NMR, several of which are identified from the UKHO. Supplementary information is gained from *The Shipwreck Index of the British Isles* (Larn and Larn 1997), and Ron Young (2003 and 2004).

In 1853 the *Marshall* (NMR 907863), an early iron German steamship travelling from Hamburg to Hull, collided with the wooden barque *Woodhouse* in thick fog at the mouth of the Humber. The *Woodhouse* was on passage from Stockholm to

Hull, and despite hailing the steamship, they collided again. The *Marshall* was not seen again, and it was presumed she sank, with a loss of 61 lives, 60 from the *Marshall* and an apprentice who fell overboard from the *Woodhouse*. A wreck located is probably that of the *Marshall* and is described as totally collapsed, well broken, with debris around (Young 2003, 159). The wreck (assuming it is the *Marshall*) is listed as a dangerous wreck, with precisely known position and notable debris (UKHO 9065).

The wreck of the *Derwent* (NMR 907863), a steel steamship, was identified by divers and positively identified through the ship's bell in October 1986. The ship was built in 1884, and was owned by the Scarborough Steamship Co., which had formed in 1881 to carry cargo and passengers between London and the North East. In 1885, on a voyage between West Hartlepool and Chatham, she encountered a force ten storm, and disappeared (Young 2003, 149). She is considered a non-dangerous wreck (UKHO 9059).

The *Earl of Beaconsfield* (NMR 907901) was wrecked in 1887 when she ran aground in dense fog near Aldbrough, on voyage from Hull to Calcutta with a cargo of grain. She was an iron four masted sailing barque, who had been launched as the *Cuba* at Glasgow in 1864, and originally belonged to the Cunard Line. The alarm was raised, and after four days tugs arrived and attempted to pull her free, but despite having earlier thrown the cargo overboard, the weather worsened, and eventually the ship was abandoned. 27 crewmen took to the lifeboats (Young 2003, 139).

Another 19th century known wreck in the area is the *Thessaly* (NMR 913055), an iron steam ship carrying raw cotton and oil-seed cake from New Orleans to Hamburg. The vessel actually caught fire off Borkum in the Freisian Islands, with the crew abandoning the ship, but the vessel then drifted across the North Sea before sinking off the Humber Estuary. Again the wreck was identified by its bell by divers (Young 2003, 174). The UKHO describes the wreck as dangerous, as comprising notable debris, with a surveyed position (UKHO 9071).

The *Dunsany* (NMR 913075 and NMR 978168) was an iron schooner rigged steam ship specially built for the coal trade in 1876 including being fitted with Price's patent self-trimming hatches. She was voyaging from Newcastle to London when she

foundered. Illustrating the importance and competitive nature of the coal trade, the *Dunsany* was loaded with 1 070 tons of gas-coal and 39 tons of bunker fuel, though at the time, no one thought she was overloaded. From the outset she was listing to port, and when she encountered gales, the list increased. Waves crashed over the side, and the hatch along with the tarpaulin covering it were washed away and soon after the water flooded into the engine room, further increasing the list. The steam tug *Monarch* of Grimsby came to her aid, but was not able to prevent her sinking. The crew took to the lifeboats, though one was capsized by the suction of the sinking ship (Young 2003, 170). Of the 17 crew, 4 were lost in the incident and a subsequent Board of Trade enquiry suggested that in future, where Price's self-trimming hatches were used, a strong set of shifting boards should also be fitted (Larn and Larn 1997). The UKHO describes the wreck as dangerous, with a surveyed position (UKHO 8742).

Two ships are recorded as lost in 1894, the *Ethel* (NMR 913080) and the *Conqueror* (NMR 1302091). The *Ethel* was sunk following a collision with the *Sudney* of Hull, and has two entries on the UKHO (UKHO 8756 and 8751). One of the entries is described as dead and likely derived from the original record of loss, though a wreck identified and last surveyed in 2007 in a similar area is likely to be this ship. The *Conqueror* was a wooden schooner voyaging from Morrison's Haven to Rochester carrying a cargo of coal, when she was stranded (Larn and Larn 1997) and is not identified on the UKHO.

Two ships wrecked in 1830 identified on the NMR also have no corresponding UKHO record. The *Mary* (NMR 1406496) was thought to be en route from Berwick-upon-Tweed to Sunderland when she stranded on Haile Sand during a gale. The incident was reported in the Newcastle Chronicle and the Durham County Advertiser, with both sources mentioning other vessels caught in the storm, including the *Busy* (NMR 1406919), en route from London to Sunderland in ballast.

The UKHO further lists 36 wrecks dating from the 19th century, although most of these are derived from documentary sources, with unreliable positions and the majority listed as dead. None of them are in Young's Comprehensive Guide to Shipwrecks of the East Coast. Of these wrecks, 10 are designated live, with 26 dead.

Only one has a precisely known position, with 6 surveyed and the rest identified as unreliable. Out of the 36, 23 are described as involved in collisions, with 18 positively identified as fishing vessels out of Grimsby from the *Shipwreck Index* (Larn and Larn 1997) with another possible 11 included in this category.

The wrecks listed as live include the *Star* (UKHO 8637), a wooden Dandy fishing vessel operating out of Grimsby which foundered following a collision, and the *John and Thomas*, another fishing vessel operating out of Grimsby, which was a wooden sloop (UKHO 8693). The Dandy *Polly Campbell* was sunk in 1896 following a collision with the brig *Gustafva* (UKHO 8795) and the Grimsby fishing vessel *Marian Francis* (UKHO 8909), a wooden Dandy, which was sunk in 1895 following a collision with the *John McIntyre*.

The probable remains of the *William Balls* are also listed on the UKHO (UKHO 8803). This was an iron steamship carrying coal between Shields and Smyrna when she foundered and was lost following a collision with the *Elba* in 1893.

Data from 305 recorded wrecks in the 19th century were obtained from the NMR polygon dataset records. These were allocated by the NMR to named locations. The vessels recorded were predominantly wooden sailing ships, with ship types including schooners, sloops, smacks, snows, brigs, brigantines and ketches. The majority are British, with French, German, Norwegian, Prussian, Russian and Swedish ships also lost in the area.

A substantial number of the ships were travelling from ports such as North and South Shields, Newcastle and Sunderland, with London again being the most frequent destination. Four ships voyaging from Riga are listed, 3 of which were *en route* to Hull, with cargoes such as flax and hemp. Many of the ships were *en route* to European destinations, such as Cherbourg and Caen, with ports further afield such as Philadelphia and Port Said also recorded. The iron barque, *Pacifique* (NMR 943005), was *en route* to Valparaiso and the iron steamship, the *William Balls* (NMR 1351561 UKHO 8803), was *en route* to Smyrna. It is possible that advancements in ship building and infrastructure, (e.g. the Suez Canal) made longer journeys possible. The *Elba* (NMR 1351581), the first steel built ship documented as lost within the study area,

was sailing from Bombay, a journey that was likely to have utilised this new route.

Approximately 70 of the vessels were carrying coal. Other cargoes include cement, chalk, china clay, building materials, and foodstuffs such as barley and wheat.

Twenty four vessels are recorded as fishing vessels, 13 operating out of Grimsby, 4 out of Hull, and others from Lowestoft, Great Yarmouth and Scarborough. The *George Bolton*, sunk in 1853, is the first recorded trawler identified in the records (NMR 1359217).

In terms of casualties, 32 of the entries list all of the crew lost, with a further 11 entries recording substantial casualties. 57 entries record that the crew was saved.

The predominant causes of wrecking again are the weather and collisions. The incidents are still reported on in the local newspapers, as well as listed in Lloyds, again giving insight not only into the incidents themselves, but the attitudes and public feeling about them at the time.

Two records of incidents involving privateers occurred in the early part of the 19th century. In 1801, the *Thames* was captured and sunk *en route* from Newcastle to London with coal, by the French privateer of 22 guns, the *Bellona*, a record that also suggests 5 other vessels captured in this incident (NMR 1376706). In 1804 the *Delaval*, a cargo vessel also *en route* from Newcastle to London, was also scuttled and burnt by a privateer (NMR 1396393). A French lugger is recorded as lost after being struck by one of her victims (NMR 1399020).

The *Thomas and Hannah*, *en route* from Newcastle, was lost along with 3 of her crew near the Dudgeon Light in 1805. The NMR entry for this event records how the master survived by clinging to the mast (NMR 1397062). The crew of the *Jane and Sarah* which also foundered off the Dudgeon Light in 1806, were saved by the *William and Elizabeth*. The incident was recorded in *The Tyne Mercury* on the 23rd September 1806;

'In the night of the 9th inst. in a heavy gale on the Deepes, near the Dodgeon Lights, the ship JANE AND SARAH, of London, coal-loaden, Alexander Campbell, master, lost all her masts, and afterwards went down. About 6 in the evening, the wind blowing a strong gale at SE, the ship carried away her bowsprit, which

was quickly followed by her masts. At the time of her foremast going away, 8 men were upon the topsailyard, who, however, escaped without any material injury. After this disaster, the ship lay like a log upon the water; the sea making a passage over her, carried away her boast, and everything that was moveable upon the deck. In this dreadful situation they remained the whole night, expecting every moment the vessel would founder with them, when about 6 in the morning, they were relieved by the WILLIAM AND ELIZABETH, of Shields, a light brig, which succeeded in taking out the people, not more than five minutes before she went to the bottom. Mr Campbell relates that when the crew had given themselves up for lost, there appearing scarcely a possibility that the vessel could keep above water till the morning, his feelings were most acutely distressed by the circumstance of his having two young boys, his sons, on board, who entreated him not to leave them, but to permit them to meet their fate enfolded in his arms.' (NMR 1340411).

The competition between the ships is illustrated by the entry for the *Isabella and Mary*, which was wrecked in 1815 *en route* from Newcastle to London with coal. *The Newcastle Courant* in the following year reported on a court case between Craig v Brown;

'In the Court of King's Bench on the 8th inst. Craig v. Brown, the plaintiff obtained a verdict of 5 000 1 damages and 40s costs, subject to a reference, for the destruction of the ship ISABELLA AND MARY, coal laden, which was run down and sunk by the defendant's ship, the ROLLA, on the passage from this port to London, in the night of the 23rd of August last.' (NMR 1402125).

Other instances that illustrate the consequences of such fierce competition are the records for collisions, whereby the other ship does not stop to aid the stricken vessel, such as in the case of the *Fly*, a schooner which was in collision with a large sloop, which 'despite their cries and entreaties for protection' sailed away. Fortunately for this crew, they were later rescued by the *Neptune* (NMR 1403344).

In addition to the documented wrecks identified from the NMR and SeaZone datasets, an unknown wreck was identified on the historic charts at the UKHO close to the Rosse Sandbanks, to the northeast of Saltfleet (Figure 5.3.5). This wreck was charted in

1842, though by the time of publication of the 1872 chart she is no longer there. A second unknown wreck in the area is depicted on the chart revision of 1880, and still there in 1888. There are no charted wrecks of a 19th century date in this area on either the SeaZone/UKHO dataset or the NMR point dataset. The NMR polygon dataset, however, records that *The Betsy* of Sunderland (NMR 1406535), quoting the *Durham Advertiser* at the time, was reported as stranded on Rose Sand in 1823, with her cargo and crew saved.

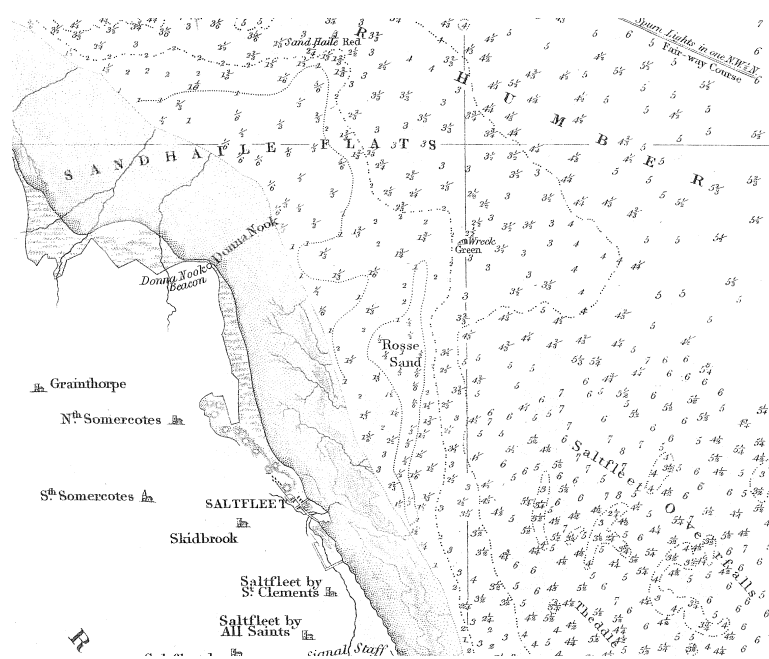


Figure 5.3.5: UKHO Admiralty Chart 1190 (part) 1842.

20th Century Pre-War Wrecks

Four ships are listed on the NMR dated as sunk in the 20th century prior to WWI. The emergence of both Hull as a fishing port, and trawling as a method of fishing is reflected in these wrecks.

Though the *Cramlington* (NMR 943102 UKHO 8682) was a steel steamship, *en route* from Newcastle to Seville with coal, coke and general cargo, the *Retriever* (NMR 913089 UKHO 8771), the *Crux* (NMR 907874 UKHO 9032) and the *Dayrian* (NMR 913083 UKHO 8763) are all listed in the *Shipwreck Index of the British Isles* as steam powered trawlers. The *Crux* was owned by the

Grimsby and North Sea Steam Trawling company and was lost in 1912 when she ran ashore. The local lifeboat was unable to reach the trawler due to adverse conditions, though 9 of the crew were rescued by the Rocket Brigade with one man drowned (150). The *Dayrian* collided with the steam trawler *Xerxes* in heavy fog in 1913 (Young 2003, 168). The *Retriever* was owned by the Hull Steam Trawler company (Larn and Larn 1997). These four ships have corresponding entries in the UKHO, though only the precise location of the *Retriever* is known, the others having approximate, surveyed and unreliable positions. The *Crux* is listed as a steam fishing vessel by the UKHO.

Additionally, the UKHO lists 12 other ships of this date, though none of these have precisely known locations. Of these 12, 5 are considered live, with 7 dead.

In 1901 the newly built HMS *Cobra*, a steel destroyer, departed from the Tyne, carrying 54 crew and 23 passengers. She was built in 1900 by Armstrong, Whitworth and co, Newcastle. As is noted in Larn and Larn (1997), ships of this length frequently found themselves supported over 2 waves in rough weather, with considerable strain on the mid section. A day after she left the Tyne, she encountered a full gale, and broke in two. Only one small dinghy escaped the wreck, in which there were 12 men. All others on board were lost. The *Cobra* was sister ship to the destroyer *Viper*, which was lost in a similar way near the Channel Islands (Larn and Larn, 1997). The UKHO entry for this ship records the position as unreliable, and suggests that it has not been possible to locate the wreck (UKHO 62792).

The *Merchiston* (UKHO 8864), a steel steamship voyaging from Bilbao to Middlesburgh in 1906 was carrying iron ore when it collided with the *Eda* and subsequently foundered (Larn and Larn 1997). The *Homer* was an iron steamship voyaging from London to Tyne in 1901 in ballast when she collided with the Russian barque *Hoppet* (UKHO 8878). The *Shipwreck Index of the British Isles* tells that at the time of collision, one of the English seamen jumped from *The Homer* to the Russian vessel, while at the same time, the Russian captain leapt on board *The Homer*. Despite the barque searching for survivors, *The Homer* went down with a loss of all lives, including the Russian captain.

The remains of a wreck, possibly the *Chelsea*, are also listed as

live on the UKHO, with contact containing notable debris (UKHO 9293). The *Chelsea* was an iron steamship in ballast and *en route* from London to Tyne when she had a collision with the *Kirkealdy* in 1903. The *Pacific* is listed on the UKHO as having capsized whilst on passage from Sunderland to Buenos Aires carrying coal (UKHO 9333).

Of the 7 wrecks listed as dead, 6 are described as steam trawlers with most of these operating out of Grimsby. The *Thomas Campbell* was a wooden Dandy, but was still a fishing vessel based at Grimsby. Of the others, some were constructed from iron, and some steel.

Even in calm conditions, collisions were possible, as illustrated by the foundering of the Dudgeon Lightship after being run down by the *Onyx*, in calm but foggy weather in 1902 (NMR 928726, Larn and Larn 1997). The *Celerity*, *en route* from Hull to Plymouth with a cargo of iron, foundered following a collision.

The Norwegian brig, *Azha*, was stranded on Skegness Middle Sand in 1912 *en route* from Arendal to South Shields carrying pit props. The crew, after being without warmth, food and sleep for four days were eventually rescued by the Skegness lifeboat, *Samuel Lewis*. As a reward for the rescue, the crew of the lifeboat received money or medals from Norway (Larn and Larn 1997, NMR 943117). Another Norwegian vessel, the *Minerva*, *en route* from Risor to Hull and also carrying pit props, had been stranded in 1900 (NMR 978225).

The *Kate and Mary* was a pilot cutter (sail) which foundered and was lost in 1906 following a collision with the *Ariadne Alexandra* (NMR 1349159).

The wooden ketch *James Garfield* sank following a collision with the iron trawler *Cardinal* of Hull, whilst at moorings in the Humber (NMR 1374670).

The *Bernadotte*, an iron steamship *en route* from Hull to Stronstad foundered and was lost following a collision with a submerged wreck (NMR 1463809).

66 wrecks are listed on the NMR polygon dataset from the 20th century pre-war period, recorded in the area with no definite location or identification. A substantial proportion of these are fishing vessels operating out of Grimsby, with other fishing towns

such as Lowestoft, Hull, Great Yarmouth and Boston also recording losses. Wooden dandys are still being used, though iron and steel steam trawlers are in the majority of vessel types lost. Losses through collisions are still frequent.

In addition to the fishing fleets, national and international trade is also illustrated in the losses. Coal was being transported as far as Buenos Aires, with Norwegian ships importing pit props to South Shields and Hull.

WWI Wrecks

There are 79 wrecks charted by SeaZone/UKHO within the study area as lost during this period, 32 which have corresponding NMR point dataset entries. 12 obstructions are also recorded of this date. 38 further wrecks are documented as lost within the offshore named locations on the NMR polygon dataset, though there is some duplication of entries between these datasets. The majority of the wrecks on the UKHO are noted to have been sunk by mines or submarines. Most of the mining losses between 1914 and 1916 are throughout the whole study area, with the only losses to mines in 1917 also recorded on the NMR, possibly suggesting that the mines were being laid tactically close to the coast during this period, specifically by UC 26, UC 47 and UC 63. Only four vessels were lost in 1918 to mines and these were all in the area outside the 12 nautical mile limit (Figure 5.3.6).

The majority of wrecks caused by submarine attacks were in 1916 and 1917, with only a few recorded in 1918. Where the submarine involved is named, they include UC 64, UB 107 and UB 112.

The majority of ship types lost during this period were trawlers, constructed from wood, iron and steel, and many were fishing vessels operating out of Grimsby and Hull. The *Wayside Flower*, a wooden motor fishing vessel was forced to stop by an unidentified German submarine, her crew made to abandon ship, after which she was scuttled (Larn and Larn 1997, NMR 1377147).

Several merchant and fishing vessels were also requisitioned by the Admiralty to serve a variety of purposes. In some cases, such as the *Margate* (NMR 1375398), a wooden trawler sunk by a U-boat in 1917, the purpose is not noted, though others, were hired as minesweepers and armed patrol vessels.

The extreme danger faced by vessels due to minefields is well illustrated by the description of the service history of the HMS *Speedy* in Young (2003, 157). He states that on the night of 25–26 August 1914 the Imperial German Navy Minelayer SMS *Nautilus* laid a minefield off the Humber and when this became known the HMS *Speedy* (UKHO 9037) was dispatched to find and clear the field, with ten hired drifters, including the HM drifter *Eyrie* (NMR 1351952), and HM drifter *Lindsell* (UKHO 61189, NMR 1351979). On 2nd September, the HM drifter *Eyrie* struck a mine, sinking her almost immediately, with 6 of her 10 crew lost. The next day, HMS *Speedy* along with HM Drifters *Lindell*, *Wishful* and *Achievable* continued the minesweeping when the *Lindsell* struck a mine, which exploded and sunk her with a loss of 4 lives. The *Speedy* had launched her boats to rescue the survivors, when she too detonated a mine, the resulting explosion sinking her rapidly. Boats from the other vessels rescued the survivors, and HMS *Spanker*, another former Torpedo-gunboat that had been converted to a minesweeper took the injured from both ships to Grimsby (Young 2003, 157).

The *William Tennant*, another steel drifter, was hired by the Admiralty as an armed patrol vessel, and was lost following a collision off the River Humber (NMR 1377033).

The *Hanna Larsen* (NMR 1375335), a steel steamship requisitioned by the Royal Navy was *en route* from London to Newcastle when she encountered the German submarine UC 39. After evasive manoeuvrings failed to get her clear, the master ordered the crew to abandon her though the firing continued from the German submarine and four men were wounded, one of whom died later. It is said that the submarine went alongside the boats and took the master and Chief Engineer prisoner, before looting the ship and attempting to sink her with bombs. The next day, UC 39 was captured by the destroyer HMS *Thrasher*, her captain killed and crew taken prisoner (Larn and Larn 1997). The two English men were released and the U-boat sunk while being towed back to port by the destroyer HMS *Itchen* (Young 2003, 160). There is discrepancy between the datasets concerning this wreck. The UKHO does not list the wreck of the *Hanna Larsen* within the study area and the NMR (polygon) position is a named position. Young, however, describes the wreck and wreck site, and gives a very different geographical position to that suggested by the NMR.

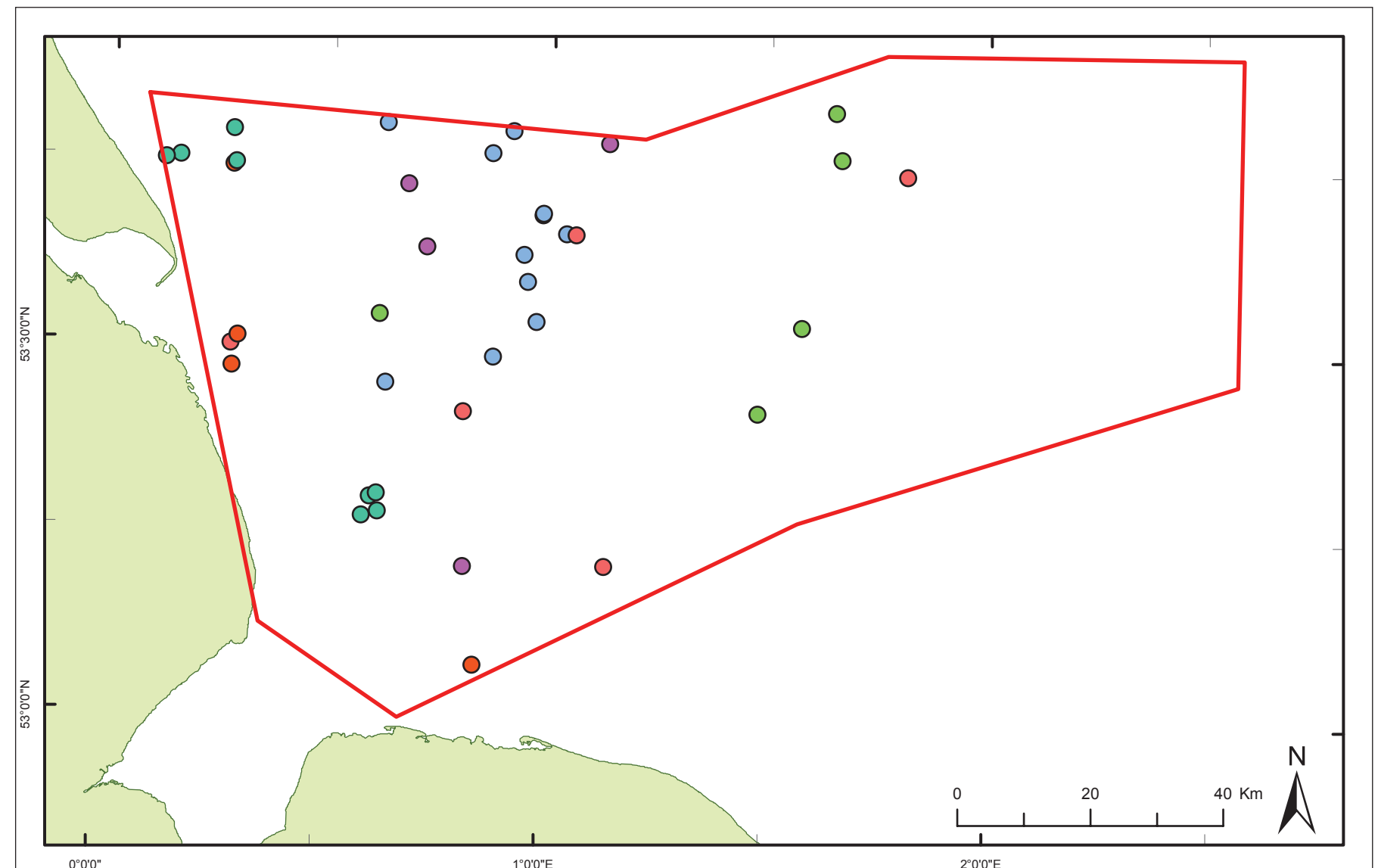
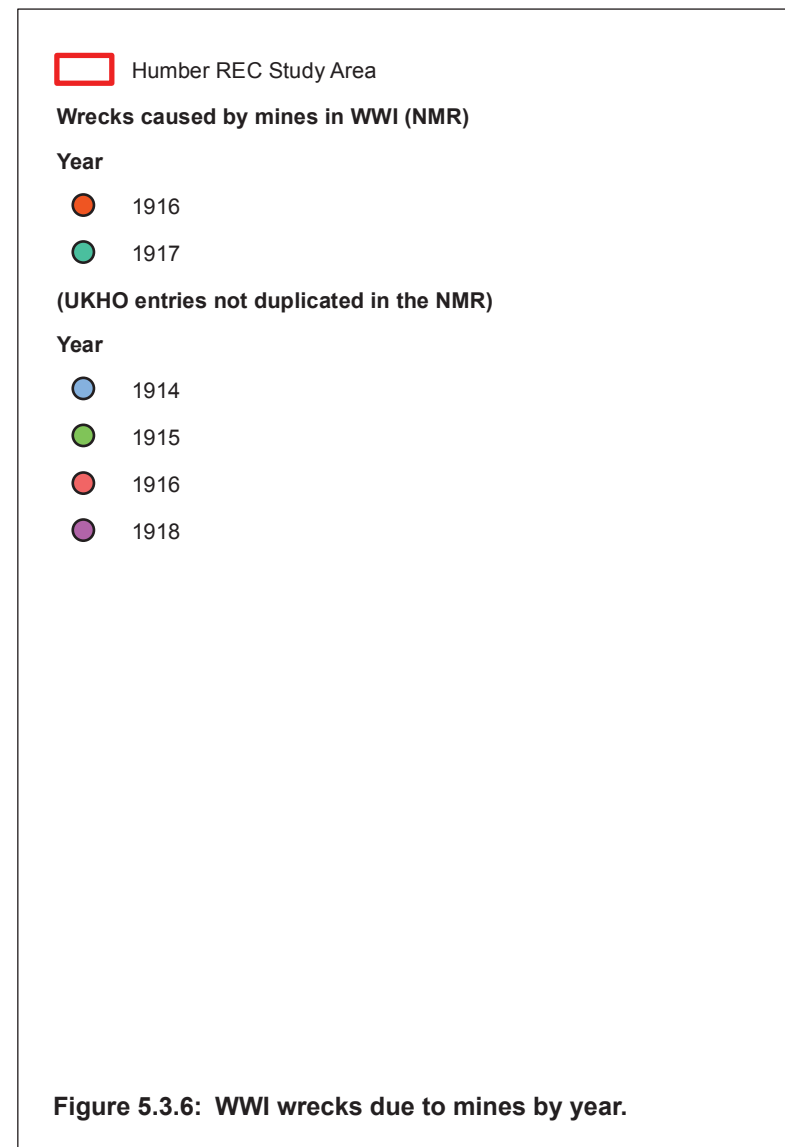
The British submarine HMS C29 is also documented as wrecked in the area after hitting a mine in 1915 (NMR 984042). The vessel was part of the 8th flotilla based at Harwich, and was part of a trawler-submarine team designed to trick U-boats by disguising the trawler and towing the submarine slightly under water. It would seem that the trawler was by herself, then when an enemy vessel was sighted the tow was slipped and the submarine would move in for the kill. The HM submarine C29 was being towed by the *Ariadne* when she hit a mine. It is possible it was a German laid mine, or part of a prohibited allied minefield (Larn and Larn 1997, Young 2003). The NMR named location is within the mouth of the Humber Estuary, however, the UKHO charts the wreck outside the study area.

WWII Wrecks

There are 110 wrecks charted by SeaZone/UKHO within the study area as lost during this period, roughly 50 of which have corresponding NMR point dataset entries. Additionally, there are 31 obstructions charted by SeaZone/UKHO, roughly 20 of which have corresponding NMR point dataset entries. There are 51 further wrecks documented as lost within the offshore named locations on the NMR polygon dataset though there is some duplication of entries between these datasets.

Assessment of the causes of wrecking incident by date demonstrates some interesting patterns, in respect to the war in general. The most common cause of wrecking is mines (Figure 5.3.7) with the majority of incidents occurring at the beginning of the war in 1940 and 1941 (Table 5.3.7). The mining incidents appear to be clustered, specifically within and immediately to the east of the Humber estuary, and within the south of the study area around the area to the south of the Wash. The location of this second cluster may be due to the location of navigational hazards in the area to the northeast of the Wash such as Docking Shoal and Race Bank and Haddock Bank, and to the fact it is on the main coastal route between the north and London. Many of the wrecks were transporting cargoes of coal and iron, and would have been funnelled through this area, making them easier targets for the Germans.

Despite 1940 being the year the Luftwaffe began its main assault on Britain, targeting the shipping, the airbases and then the cities,



only one ship, the *Keynes* (UKHO 8879) is recorded as lost due to attack by enemy aircraft within the study area in this year, and this was lost on 11th January 1940, before the main brunt of the attack. Of the 35 other wrecks recorded as due to attacks by aircraft (bombing and gunfire), 30 were during 1941, with 5 recorded in 1942.

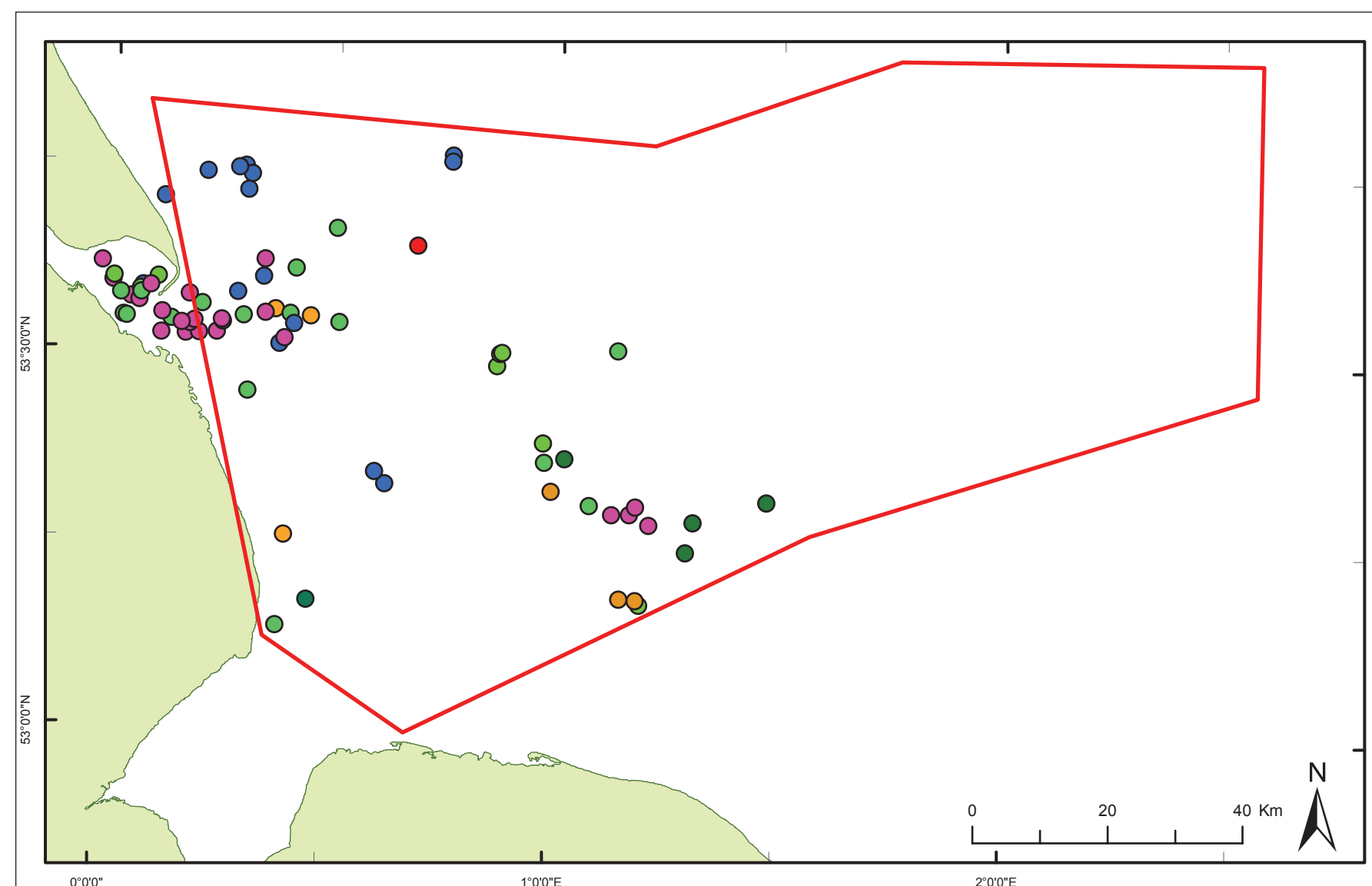
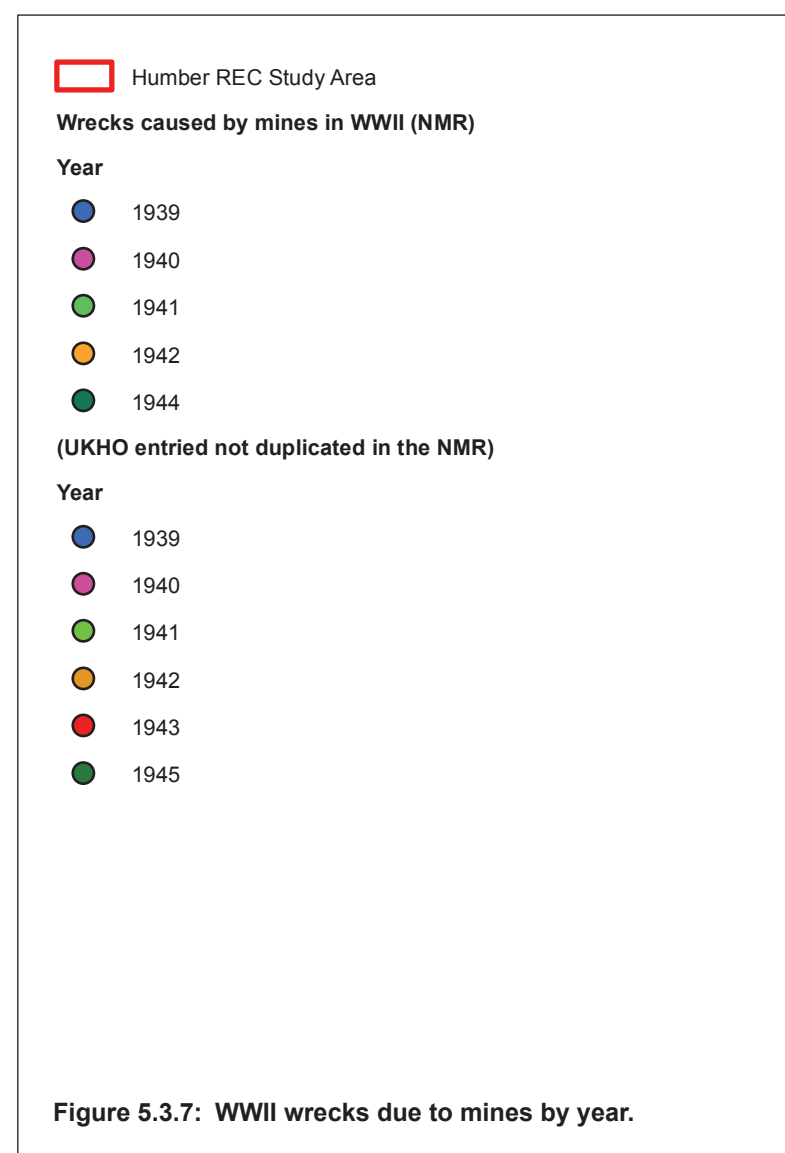
One such attack was on the *Vechstroom* (UKHO 8886 NMR 1390420), a Dutch steel steam ship *en route* from Goole to London with coal. She was attacked by the Luftwaffe in September 1941, though none of her crew were hurt (Larn and Larn 1997, Young 2004, 146).

Another successful form of attack in 1941 were the E-boats, which sunk 13 vessels within the study area. Apart from 1 successful sinking in 1944, these boats were only successful during this year. Where the locations of these wrecks is possibly accurate (ie from the SeaZone/ UKHO data, and NMR point data) these can also be seen to be clustered in an area similar to the mines.

Submarines also posed a hazard. Mostly this was from mine laying activities though, with only a few recorded losses due to torpedoes. One such loss was the *British Councillor* (UKHO 8897 NMR 1378245), a steel tanker *en route* from Tyne to Abadan in 1940. She was part of convoy SN 8442 when she was torpedoed and

sunk by U-59. The crew are noted to have safely abandoned ship and were picked up by escort vessels (Young 2004, 142).

The HMS *Warland* (UKHO 8921) was an armed steel trawler, which had been requisitioned by the Admiralty during WWI and converted to a bomb-thrower/minesweeper, and then returned to her owner after the war. She was requisitioned again during WWII, this time as an anti-submarine patrol vessel, fitted with one forward deck gun that fired 12 pound shells. She was patrolling off the Humber in 1942 when she was attacked by German aircraft. There is no mention of the fate of the crew (Larn and Larn 1997, Young 2004, 214).



As had happened in WWI, many ships were requisitioned by the Admiralty to serve a variety of purposes, such as patrol, mine sweepers, and armoured convoys. The HMS *Fleet Tender C* (UKHO 9329 NMR 943161) was also requisitioned as a decoy vessel during this period, having had an interesting history. She was built in 1911 as the *Zealandic* and was chartered as an immigrant ship in 1913 by the West Australian government. She was requisitioned in 1917 for the war effort, and returned to civilian duty in 1919. She changed owners, and names, and in 1932 put on the Australian run. Young suggests she was purchased by the Admiralty in 1939 as a fleet tender, but following the sinking of the HMS *Hermes*, an aircraft carrier, in 1941 she

was converted to resemble this ship to confuse the enemy (2004, 218), though the *Shipwreck Index of the British Isles* records she was hired by the Admiralty up to the sinking of the HMS *Hermes* then purchased for the conversion (Larn and Larn 1997). Her fate illustrates another hazard that plagued shipping during this period, that of previously wrecked vessels. On 2nd June 1941, while she was *en route* to Chatham to be reconverted back, she struck the wreck of the steam tanker *Ahamo* (UKHO 9328 NMR 943166). The *Ahamo* had detonated a mine in April of that year, with the loss of 13 of her crew. The HMS *Fleet Tender C* stuck fast, and 2 days later, was torpedoed and sunk by German E-boats (Young 2004, 218).

The *Gluckauf* (UKHO 67200 NMR 1381466) is also recorded as sunk after hitting a submerged wreck, as is the *Dryburgh* (UKHO 8876 NMR 907866). The *Dryburgh* was a steel steam ship *en route* from Leith to Antwerp with a cargo of coal and horsemeat when she struck the wreck of the *Canada* which had gone down 8 days earlier. The *Canada* herself (UKHO 8881 NMR 907870) was a steel motor vessel *en route* from Vancouver to Gothenburg when she hit a mine. Her crew was saved in the incident, though no mention is made of the fate of the crew of the *Dryburgh* (Larn and Larn 1997).

Though travelling in convoy enhanced the chances of the ships passing through the study area safely, it was still perilous. The

Horsted (UKHO 8912 NMR 970899) was part of a convoy in December 1939 when she was rocked by a massive explosion, killing 3 of her crew with 2 dying later from their injuries. It was likely she hit a mine, though the cause was not determined (Young 2004, 130).

The *City of Birmingham* (UKHO 8722 NMR 913063 and NMR 945151) was a 5 309-ton steel steamship that detonated a mine and was lost off the Humber estuary in August 1940. She was *en route* from Beira (Mozambique) to Hull via the North Coast of Scotland with a huge cargo comprising wool, tea, tobacco, canned fruit, asbestos, an unspecified amount of ammunition and 2 550 tons of copper and tin ingots. Her entire crew of 79, along with one naval rating, abandoned ship and were saved. Salvage operations began almost immediately, and also continued after the end of the war, and by September 1949 almost £2 million of her copper and tin ingots had been recovered (Young 2004, 196).

In addition to shipwrecks, there are 73 documented aircraft losses from this period on the NMR polygon dataset (Table 5.3.6). As the locational attributes of this dataset are imprecise, little can be inferred from their spatial distribution. Temporally, however, they occupy a range of dates throughout the war, and are represented by a number of different aircraft types, both British and German. It is likely that many more aircraft were lost than is recorded on the legacy datasets, as comparison with private datasets suggests many more aircraft lost than are currently recorded.

Two aircraft are documented as lost in 1939, one a heavy bomber type Wellington MK 1A N2983 that was damaged by fighters and ditched off Grimsby (NMR 1328998), and a German Heinkel HE 111 bomber, that was part of the coast flying corps (NMR 1399685).

During 1940 11 British and 5 German aircraft are documented lost. Of the British losses, the majority are bombers type Hampden Mk I and Blenheim Mk IV, with a Battle Mk I and a fighter plane, Spitfire Mk I also recorded. Of the German planes, they were Heinkels and Dorniers, on a variety of missions including a sortie to Hull, and one which was *en route* to Birmingham (NMR 1393564).

Thirteen British aircraft and 4 German aircraft are recorded lost in 1941. The type of aircraft changed during this year, and while

Data Source	1939	1940	1941	1942	1943	1944	1945	total
UKHO (non NMR)	3	11	7	5	1	1	4	32
NMR point	11	11	15	3	0	1	0	41
NMR polygon	3	17	12	3	1	1	2	41
Totals	17	39	34	11	2	3	6	114

Table 5.3.7: WWII Losses due to Mines.

2 bombers, type Hampden Mk 1 are recorded, a new type of bomber in the Wellington Mk IC is recorded, and many of the other documented losses are of fighters and heavy bombers. The fighters are represented by Hurricanes MK1 and another Spitfire. Three Whitley MK V, British heavy bombers are listed as lost. Of the German aircraft, there is also a change in type. A Dornier Do17 and a Heinkel He111 are listed, with 2 German Junkers Ju88 also recorded as shot down.

In 1942 the general type of British aircraft lost is similar, though in the case of the Wellingtons Mk 1C, Mk II, Mk III and MK IV types are documented. Additional types include a Halifax Mk II. Only 1 German aircraft is recorded lost in this year.

The British aircraft lost during 1943 shows a nearly complete change in aircraft type. In this year 7 aircraft are documented, a Beaufighter Mk X, a Boston Mk IIIA, a Halifax Mk II, a Halifax Mk V, two Lancaster bombers and a Lysander MkIIA all recorded lost. The type of German planes remains similar, with later versions of the Dornier (Do217) and Junkers (Ju188) lost comprising 4 documented wreck sites.

Additional British aircraft types in 1944 include a Mosquito MkII, two Stirling MkIII and a Tiger Moth Mk 2, with 10 losses documented in total. One German Heinkel He177 is recorded lost. Of the 5 losses recorded in 1945, all were British, with 3 being Lancaster Mk111.

Later Wrecks and Undated Wrecks and Obstructions

As the SeaZone/UKHO data charts all wrecks and obstructions there are several in the area that post-date WWII. While these have not been included in the assessment, it is important to acknowledge them, both as potential graves if there was a loss of

life associated with the wrecking incident, and also as potentially older vessels as the wrecks are categorised to the date they sunk, rather than the date they were built.

There are also substantial numbers of wrecks and obstructions with no additional information within the study area. These wrecks have the potential to be of any date, and any further information gained on them, by diving, research or survey will add to the body of evidence for maritime archaeology within the area.

As the charted and documented wrecks are not likely to be the whole record, there is also the potential for other unidentified wrecks of all periods to be present within the study area.

5.4 Prehistoric Results

5.4.1 Results — Palaeolandscapes — Main Geophysical Survey Lines

After examining the available data, it was determined that it would be suitable for the focused analysis of the post-Devensian (i.e. the last glacial period ending circa 10 000 BP) geographic and geomorphic features. The features of the post-Devensian landscape may also be observable in places due to the marine processes active during the Holocene (10 000 BP to present) transgression of the Study Area and those taking place subsequently. This erosion event is clearly observable in several seismic lines.

The initial examination of the baseline conditions appeared to show that the shallow sediments in the Study Area were laid down during three main phases that could be easily identified on a regional scale within the dataset.

Seabed sediments. These consist of slightly shelly sand to very gravelly sand. The general thickness of this layer ranges across the study area (Cameron *et al.* 1992). The geotechnical vibrocore assessment indicates that these sediments are marine in origin and were deposited during and after the Holocene transgression.

Holocene Deposits. These deposits reach a thickness of over 5 m in localised areas. However they are absent or confined to small localised areas in the extreme west of the Study Area, especially near the Humber coastline. The vibrocore assessment indicates that these deposits were emplaced during the Holocene emergence. More detail on these sediments is available in the archaeo-environmental report.

The Bolders Bank Formation (BBK). Directly underlying either the seabed sediments or Holocene deposits depending on local conditions. This deposit consists of hard clay with boulders, gravel and sand varying proportions across the Study Area, it is up to 25 m in thickness.

Where the Bolders Bank Formation was not present the Holocene deposits (and seabed sediments) were observed to overlie deposits older than Late Pleistocene age (~18 000 BP).

Standard geoarchaeological interpretation was undertaken to identify any unknown features such as palaeochannels, palaeo-valleys and peat deposits (with potential for the preservation of organic material and sub-fossil environmental remains such as pollen) that may have survived these processes. Such features were visually identified as strong delineating boundaries within different geological layers within the seismic data. The digital SEG-Y records were examined for any strong distinct negative peaks because these often represent peat deposits (Plets *et al.* 2007).

The Boomer lines provided sufficient detail for the identification and characterisation of large palaeogeographic features and landscape surfaces. Such features were picked from the seismic data. Several palaeochannel features were identified (see Figures 5.4.1 and 5.4.2 for examples) and are particularly significant on the basis of their likely preservation of archaeoenvironmental evidence. Palaeochannels and other palaeolandscape features of significance were exported with the shotpoint and spatial

information into the GIS in order to allow their position to be viewed within the overall context of the Study Area and in conjunction with other data sets (see Figure 5.4.3). Such visualisation facilitated the cross correlation and data validation of the interpreted horizons. Where areas of archaeological interest were observed within the seismic data, and sufficient data density allowed, gridded surfaces were generated from the picked horizons within SMT Kingdom and interpolated to facilitate a 3D representation of the localised prehistoric landscape topography.

Overall, there were 223 areas identified where the 2D seismic data collected during the survey suggested the presence of features related to archaeologically significant channels, 84 separate areas relating to Holocene land surfaces, and 4 areas where the data indicated the presence of possible lacustrine features of archaeological significance. The palaeochannels observed within the Humber REC data seem to be primarily clustered in the more offshore sections of the Study Area, and especially the southern reaches of its central zone. Another prominent cluster occurs in the north eastern area. Whilst these seem to show general trends caution must be advised due to the relatively small proportion of the total Study Area which they actually cover, and hence other clusters of palaeogeographic features may occur outside of these areas.

The most significant cluster was observed in the south western area, some 50 km offshore of the East Anglian Coast (Figure 5.4.4). This area was initially highlighted as a possible area of potential from the Desk Based Report because of the recovery of peat material in a BGS core. The survey lines from this area record a multitude of channels and land surfaces, that are C14 dated to the Mesolithic period (see section 5.6). The data clearly illustrate a number of palaeochannels crossing the area, flowing to the north. The most significant of these systems has been provisionally named 'Reid River', and a local landscape interpretation of this site is presented in Figure 5.4.5. This system alone represents an important resource, with layers of archaeoenvironmental potential visible within the seismic data that was subsequently proven during the ground truthing campaign. Since a considerable number of the fluvial systems within the associated character zone contain this structure, it is likely that this high archaeoenvironmental potential extends over a considerable proportion of this area.

The internal structure of the channels illustrates a variety of environments, with areas of channel development and migration present. Areas of slow moving water and river bank are also indicated by the data. In several places it is possible to follow the palaeolandscape across a considerable distance. However it is also significant to note that erosion of these deposits may well be occurring. A re-coring of the initial BGS sample site only recovered pre-Holocene material located at the base of the sequence. This possibility of erosion is supported in the seismic profile evidence where the effects of erosion on the Holocene landscape can be observed (see Figure 5.4.5).

5.4.2 Archaeological Detail Areas — Area 1

Archaeological 'Area 1' was specifically targeted to test the results of the North Sea Palaeolandscape Project (NSPP) at the request of English Heritage. The survey grid was positioned over a large palaeochannel floodplain recorded in part for the first time by the NSPP. Significantly this feature was not expressed in bathymetric data available to the NSPP. The palaeochannel floodplain as visualised within the 3D dataset is a maximum of 500m wide, although the internal structures of this floodplain and the channel itself remained irresolvable. However this feature was of sufficient size to be considered as representing one of the significant drainage channel features within the archaeological landscape of this region. In addition since the channel has been observed to connect to the palaeocoastline of this region, the channel was likely to have represented a major route way for human movement within this area. The palaeoenvironmental record of the channel therefore is likely to be significant and the location in an area with an extreme scarcity of such information made the identification of this feature noteworthy.

The detailed geophysical survey undertaken as part of the Humber REC therefore sought to relocate this palaeochannel floodplain, and test the results of the NSPP. Through the provision of additional information a ground truthing of the existing landscape interpretation for this region could be achieved. In addition it was hoped that any new data could allow the resolution of any internal structures of the feature which were previously unresolved, most specifically the location of the channel, to be refined. Such information would be used in a later stage of the project to provide insight into the likely locations of preservation

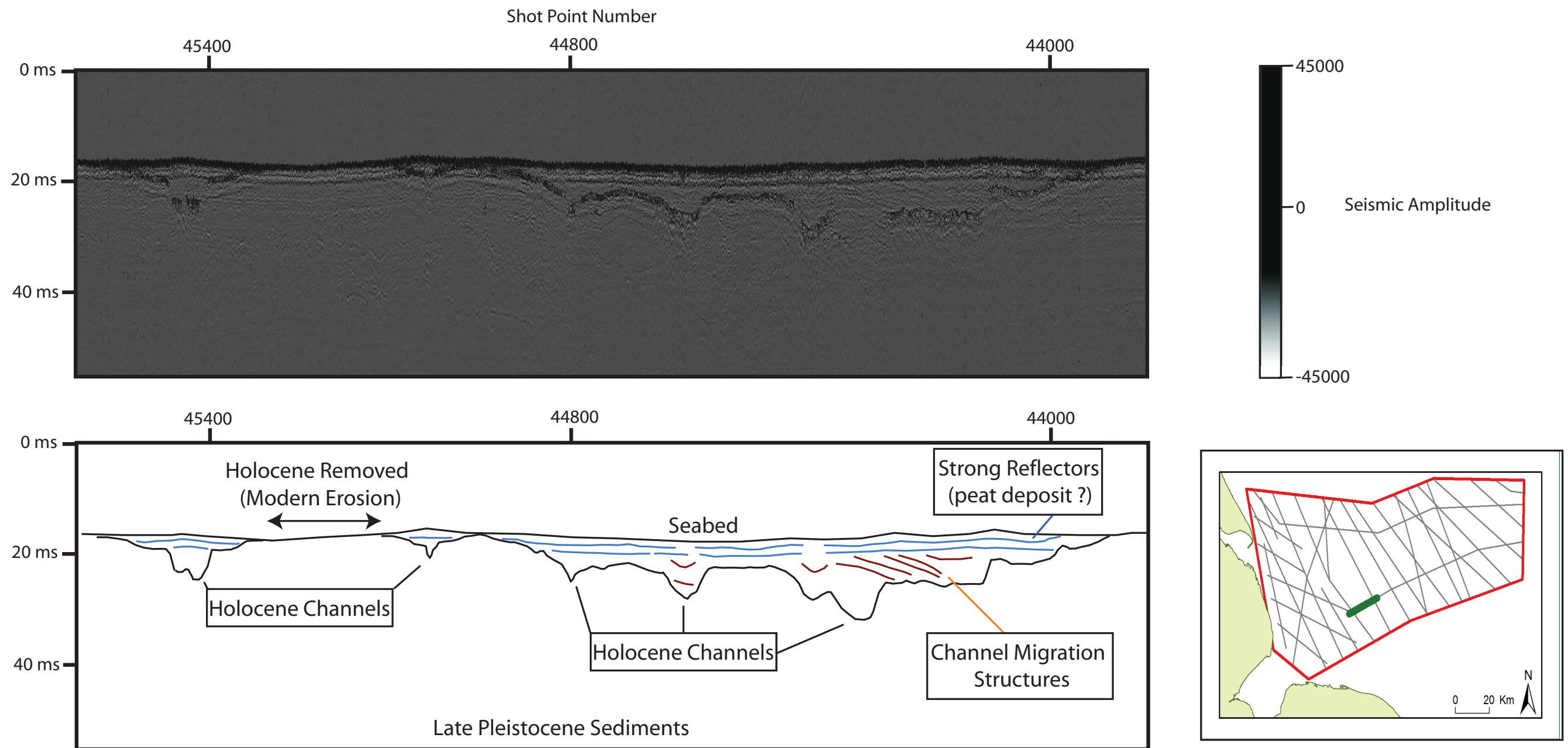


Figure 5.4.1: Palaeochannel system located by the survey Line 18_100N.

of deposits of archaeological significance which would be cored for archaeoenvironmental assessment.

The shallow seismic work for the survey was performed by the *Gardline Vessel Vigilant* during the winter of 2008/2009. For the area targeted as part of this research, the seismic data was acquired in a grid pattern of 30 m by 60 m. The Detail Survey

Area 1 covers a rectangular area of approximately 0.4 km² with a mean water depth of approximately 30 m. Unfortunately during the survey the grid had to be adapted for operational reasons which meant that data was no longer collected along transects perpendicular to the main palaeochannel. Thus the data resolution with respect to the main feature was less than optimal. Additionally, the prevailing bad weather during the survey resulted in seismic

lines acquired on southwards headings were poor. However, northwards-heading lines were of sufficient quality to be useful. Despite these limitations, the northern most section of the survey grid successfully intersected the feature identified previously by the NSPP and thus it was possible to address the aim of the survey by validating the results of the NSPP by sampling.

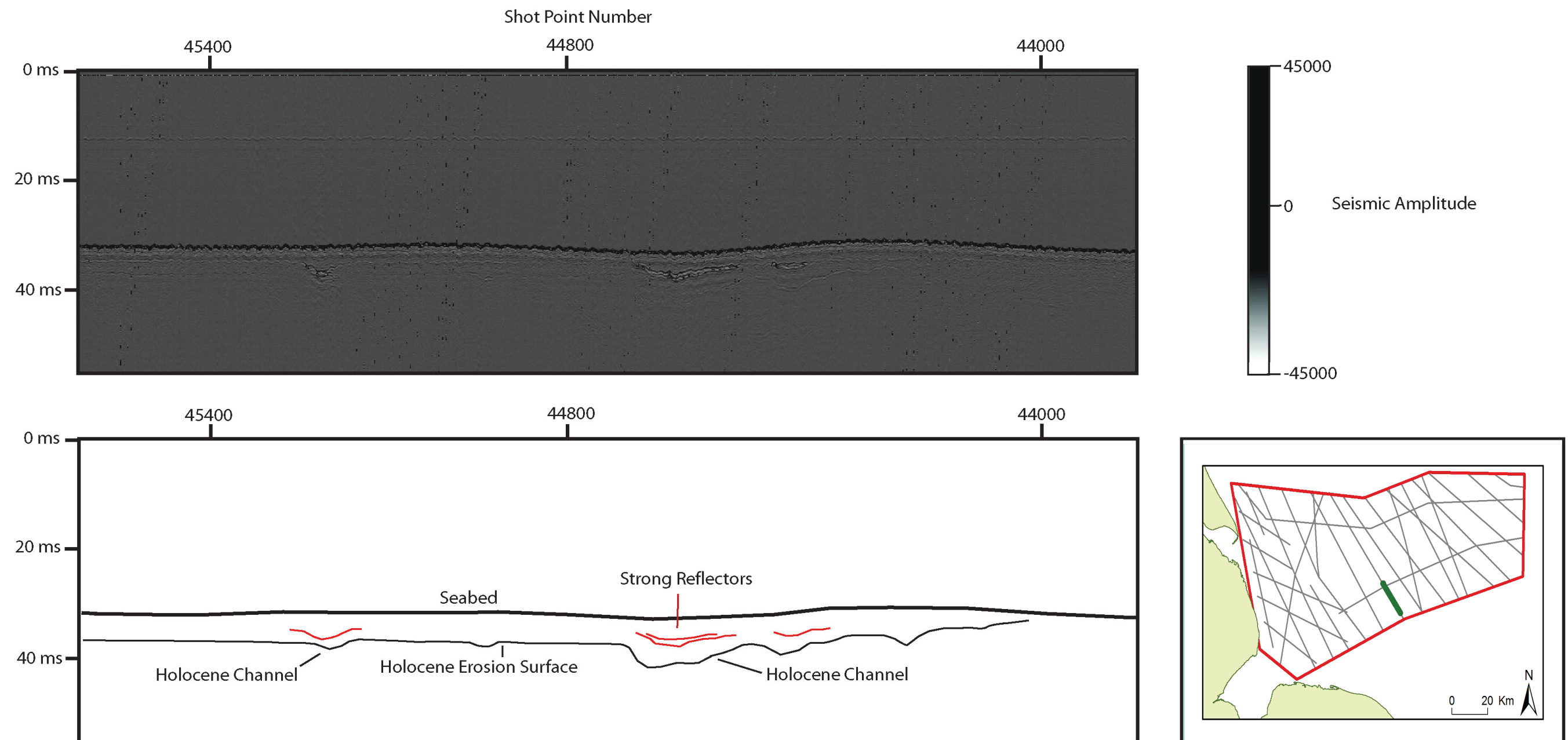


Figure 5.4.2: Palaeochannel located by the survey Line 11A.

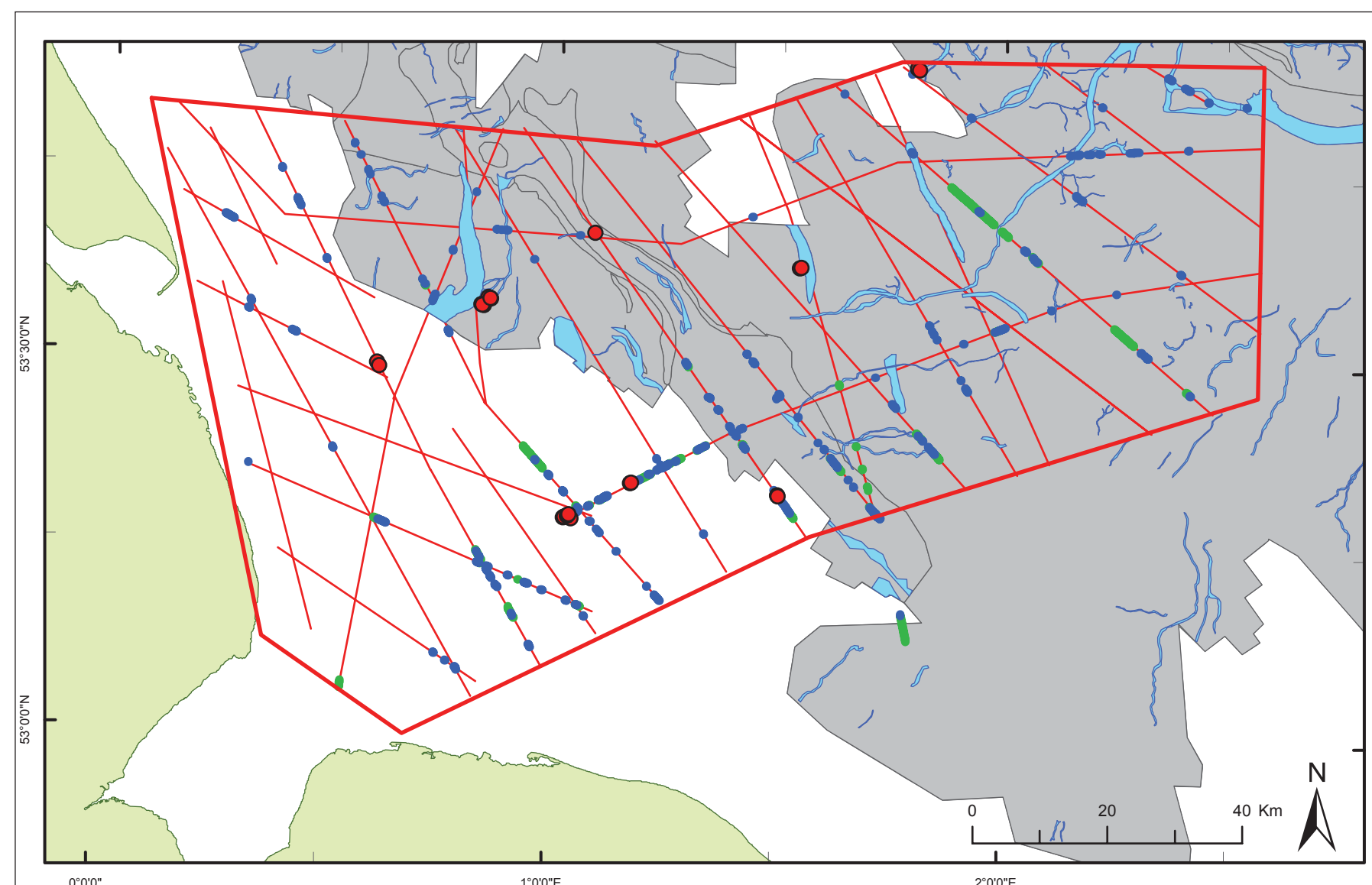
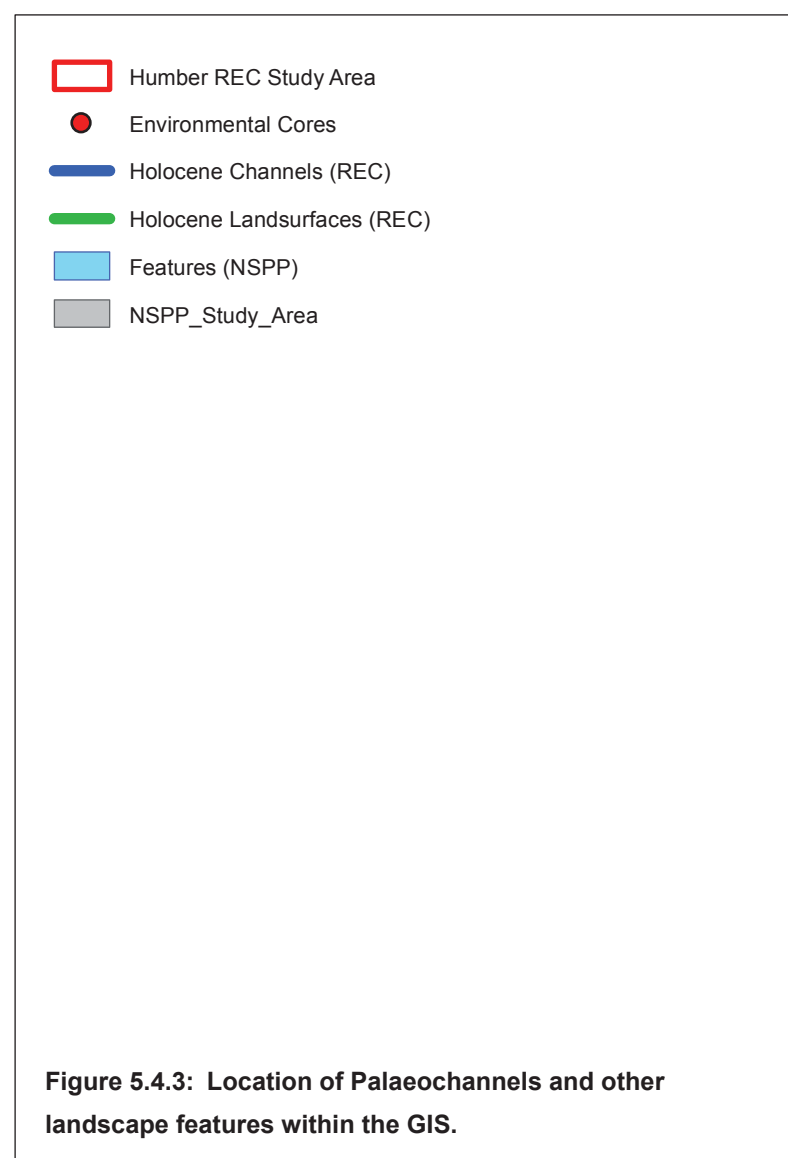
Results

Initial survey of the seabed surface by multibeam echo sounder confirmed that the features located during the NSPP were not visible on the seabed at this location (see Figure 5.4.6), with the seabed surface comprising a number of recent natural scours and sand structures. This is a highly significant result since it confirms the findings of the NSPP and thus supports the regional observations

made. This validation will be invaluable in assisting the production of the regional characterisation through the identification of the nature and morphology of the feature due to the confirmation of the previous NSPP results.

The main channel was clearly observable in some of the new 2D data (Figure 5.4.7). It is characterised in places by thin continuous

dipping reflectors which are suggestive of a migrating channel system. This feature was located within the area defined by the NSPP as an area of floodplain. Closer examination of the 2D data also showed a correspondence to an anomalous area in the 3D dataset which is thought to represent a channel bar (Figure 5.4.8). The base of the main channel was indistinct in many of the new survey lines, and this prevented full modelling of the channel



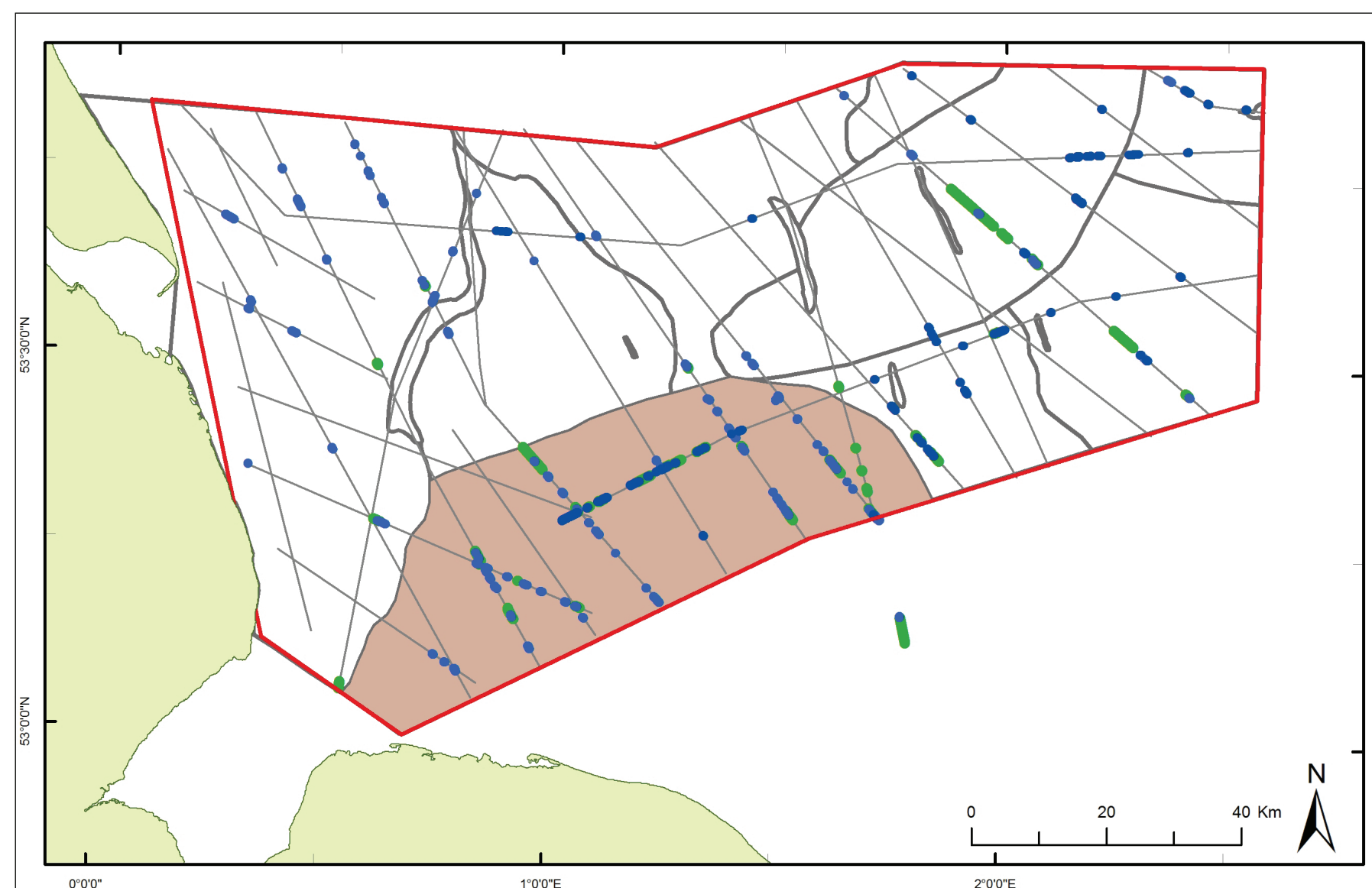
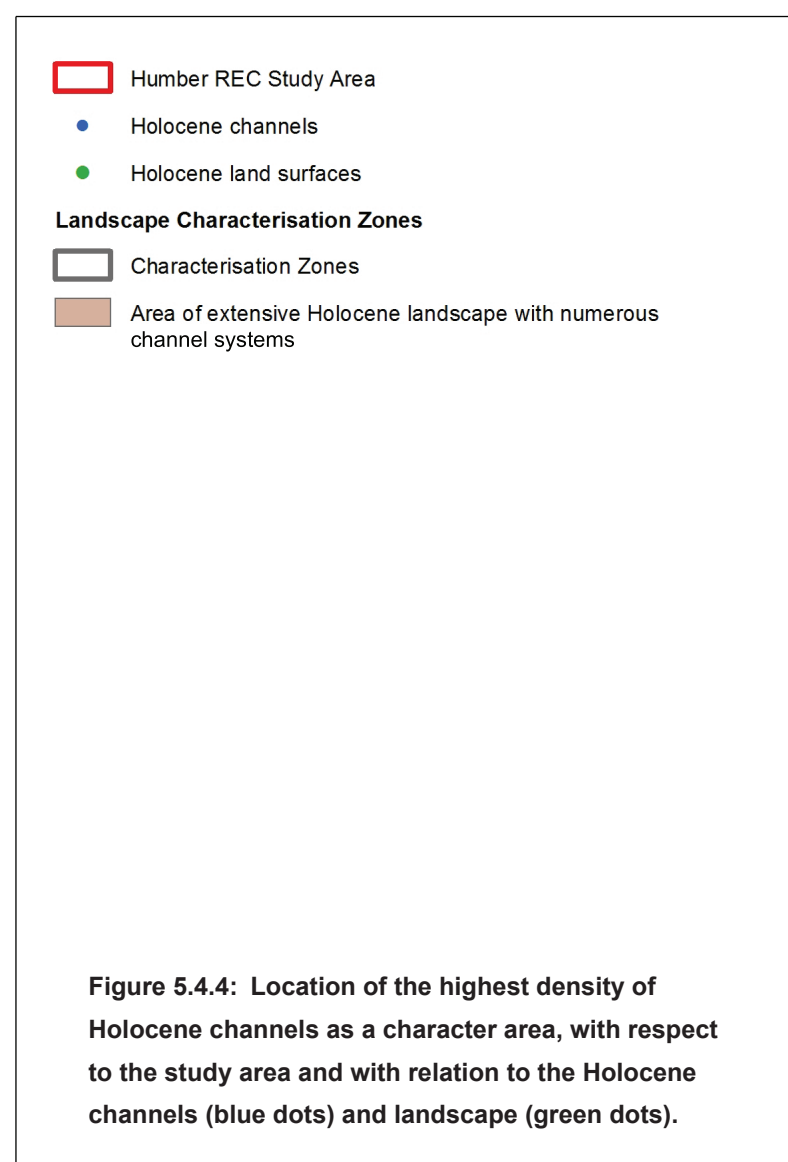
system based purely on the 2D seismic data. However, sufficient lines with suitable detail were obtained to allow the gross channel morphology to be observed, with the main channel being recorded as approximately 185 m wide. This was noted to be directly comparable to channels of similar age previously observed on the Dogger Bank.

The main NSPP dataset shows the main palaeochannel floodplain to pass through this area on a roughly north-easterly alignment, and appears to be joined on the western side to a smaller channel system. This interpretation is supported by the high resolution survey of the Humber REC. This result is

significant since it records the presence of a smaller channel structure crossing over the floodplain and joining with the main channel, which was previously unrecognised. This new finding therefore increases the detail of the palaeolandscape which forms the basis for cultural interpretation. The data facilitates the identification of the internal structure of the fluvial feature and areas of archaeological and archaeoenvironmental potential, such as the banks and the bar. From it two transects were identified as suitable areas for coring during the ground truthing program.

The core recovered from this sedimentary system, consisted of a red brown basal clay (2.0–1.34 m) overlain by a grey black

mottled silt (1.43–1.25 m) passes up into grey silts with fine sands that in turn are overlain by coarse shell rich sands. All the Ostracod samples yielded assemblages that suggested euryhaline-brackish salinities and the influence of both upper and lower saltmarsh. It is thought therefore that the cores only sampled the uppermost part of this channel and recovered samples relating to its inundation. Given the Optically Stimulated Luminescence (OSL) date of 9.5 Ka BP \pm 0.8 Ka (GL09068) taken from a nearby OSL core from this site, it is thought that the onset of submergence for this region is consistent with the models of Shennan (2000).



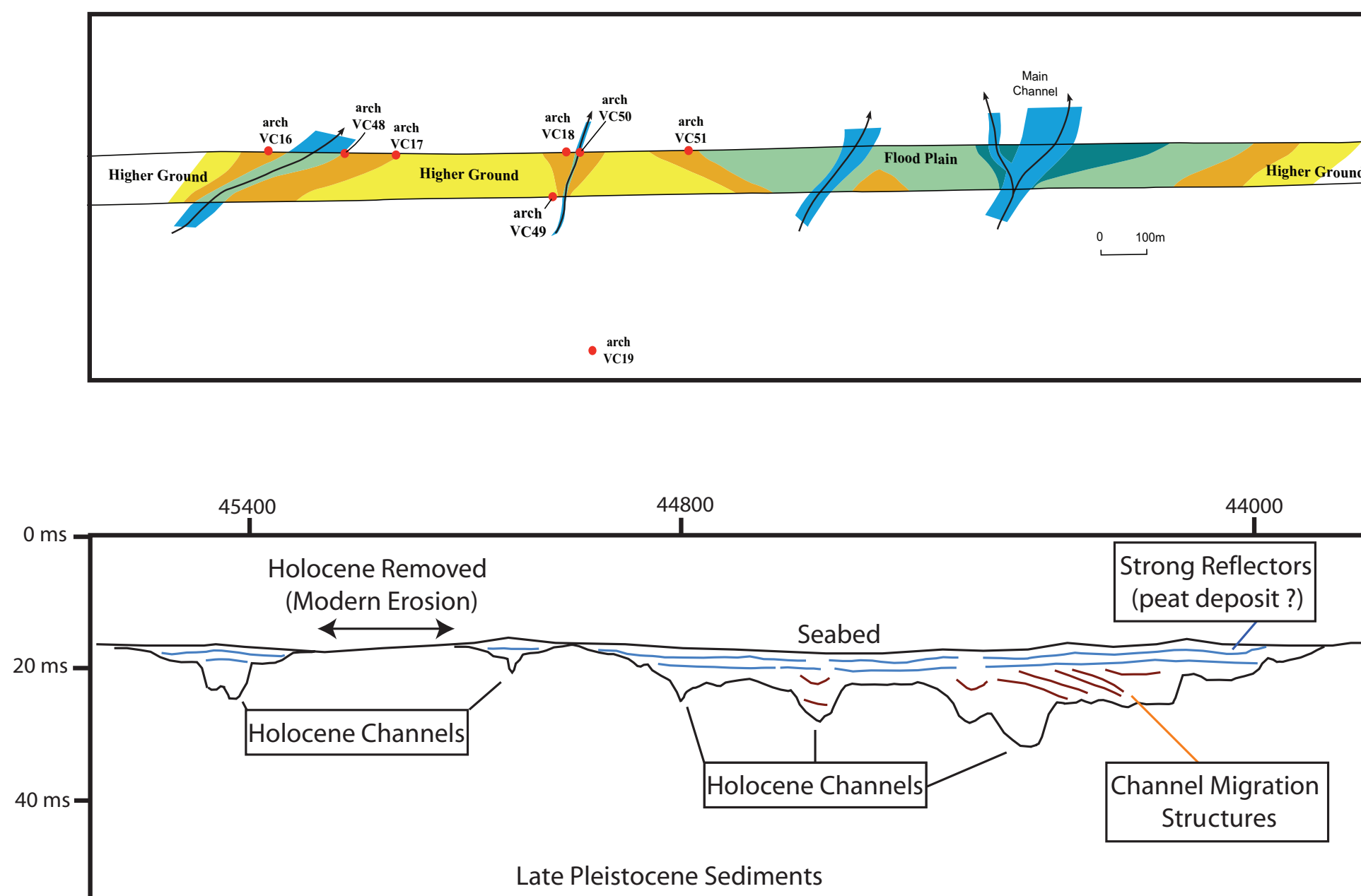
The channel feature is considered therefore to have been active during the early Mesolithic. Unfortunately due to only shallow penetration (2.0 m) of these cores, material earlier than 9.5 Ka BP was not sampled. Therefore an initial date for fluvial activity cannot be produced, but must be before 9.5 Ka BP and after the end of the Last Glaciation.

5.4.3 Archaeological Detail Areas — Area 2

Archaeological 'Area 2' was proposed to cover the features located on both the North Sea Palaeolandscape Project database and the SeaZone Bathymetry. The features were

thought to represent a palaeochannel. Unfortunately the features located in the Palaeolandscape database are within an area of data striping, and so its resolution was poor. A proposed age of Upper Palaeolithic/Early Mesolithic was assigned to this feature based upon its position and morphology. A strong spatial correspondence can be observed with a feature in the SeaZone bathymetry, suggesting that it has an obvious seabed expression. Such an expression suggests that any archaeologically significant sediments would be near surface. This, together with the data striping over the survey area, make the feature a prime location for more detailed investigation.

The detailed geophysical survey in Area 2 therefore sought to locate the palaeochannel and to provide contextual information. Through the provision of additional information a ground truthing of the existing landscape archaeological interpretation for this region could be achieved. This survey was redesigned during the project through consultation between the BGS and Birmingham University for operational reasons. As a result, additional lines were inserted in key areas to optimise the return and to reduce areas of uncertainty. For the area targeted as part of this research, the seismic data was acquired in a grid pattern utilising a 60 m x 60 m grid (in deeper areas this was increased to 60 m x 120 m). The



Plan and interpretation view
of cross section through
"Reid River Site"
(Route 18-100N)

Figure 5.4.5: Landscape interpretation of Reid River area (Route 18-100N). This plan view clearly illustrates the morphology of this important system.

survey area covers a rectangular area of approximately 0.4 km² with a mean water depth of approximately 30 m. Despite the weather conditions and their effect upon the data, it is felt that the data returned by the survey is sufficient to have achieved a good resolution of the feature.

Results

From the acquired multibeam data, it was apparent that the palaeochannel structure had a well defined shape and bathymetric expression. Apparent within the multibeam data was a bathymetric deepening of the structure in a westward direction towards the Silver Pit. The multibeam data also highlighted a small channel previously undetected in the western portion of the data, which is expressed

by the green oval structure in the extreme east of the survey in Figure 5.4.9. The bathymetric expression of the main structure suggests it to have been enlarged by erosion from tidal currents.

Within the main palaeochannel structure, a clear erosion base can be seen delimiting the structure from the surrounding material (Figure 5.4.10). The structure can be clearly seen to cut through an earlier geological boundary, as well as the inferred Late

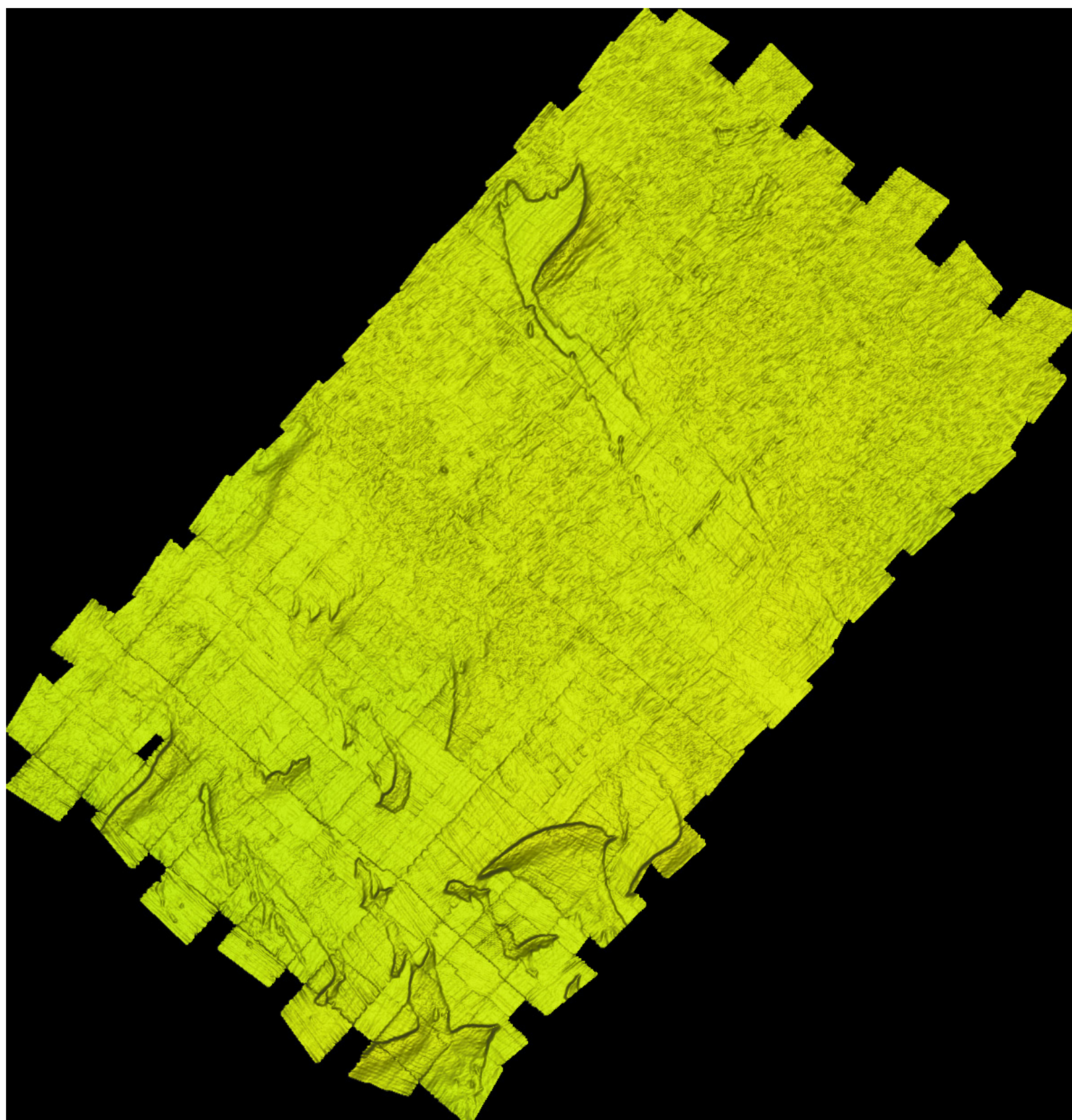


Figure 5.4.6: Archaeology Area 1 — Multibeam image of seabed.

Pleistocene/Holocene boundary (Figure 5.4.10). From this the structure can be tentatively interpreted in being Late Pleistocene in age. The structure contains multiple internal surfaces which relate in part to channel activity. Minor surfaces are observed above this which relate to the infilling of the structure.

The minor channel structure is fainter in expression, with the erosional base less clearly defined (Figure 5.4.11). Only minor faint reflectors can be discerned within the data, and these provide insufficient evidence for internal structures. One minor incision surface can also be discerned which may suggest later reactivation of this channel, possibly during the earliest Holocene. The minor channel structure can be observed to join with the main channel, and thus is considered to be of similar age. The structure was therefore interpreted on the basis of the geophysical data as being a Late Pleistocene fluvial system which may have been reactivated during the Holocene. As this result was similar to the previous interpretation, a series of core locations were defined for sampling during ground truthing program.

OSL dates obtained from cores guided by this geophysical work return a determination of 19 Ka BP \pm 3 Ka (GL09075) for this structure, and thus confirms the geophysical interpretation. This date corroborates and validates the geophysical work and shows this structure as originating from the Late Pleistocene. Due to feldspar contamination of the OSL date (GL09074) within the section of core containing the later activity, it is not yet possible to determine if this dates from the Holocene, or the Late Pleistocene.

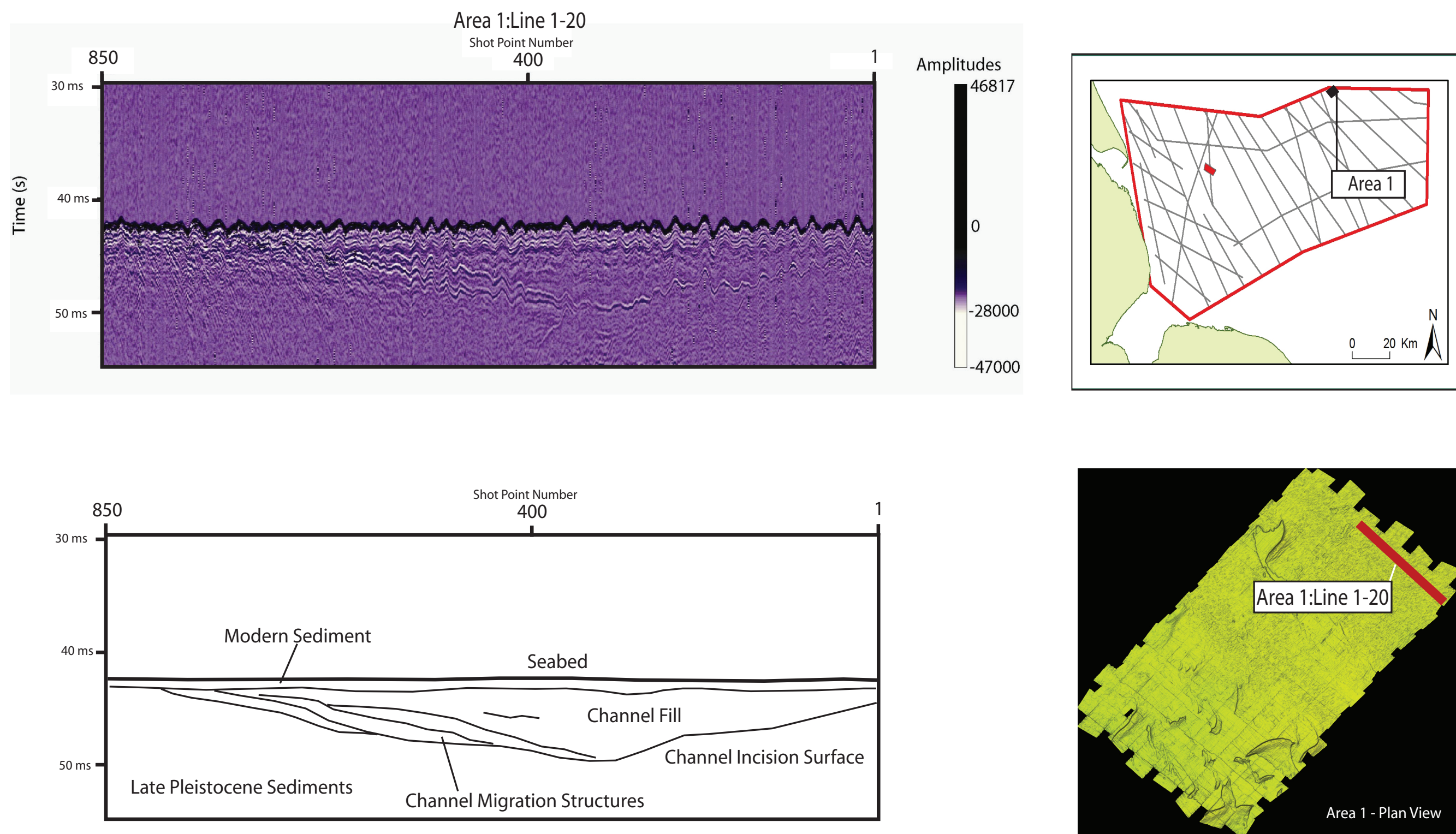


Figure 5.4.7: Seismic profile through the main Palaeochannel (Area 1).

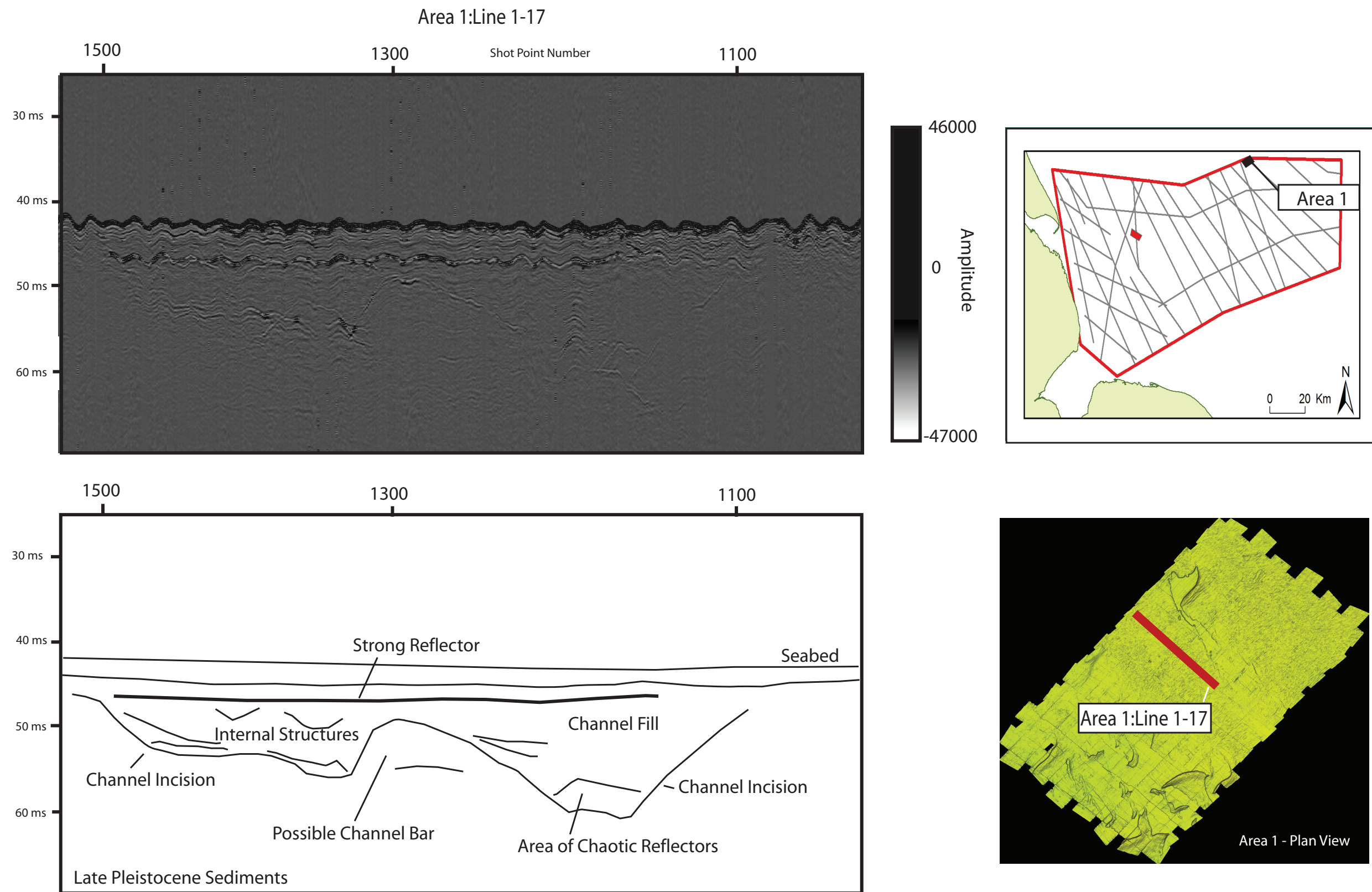


Figure 5.4.8: Seismic profile through the channel reveals the presence of a possible channel bar within the system (Area 1).

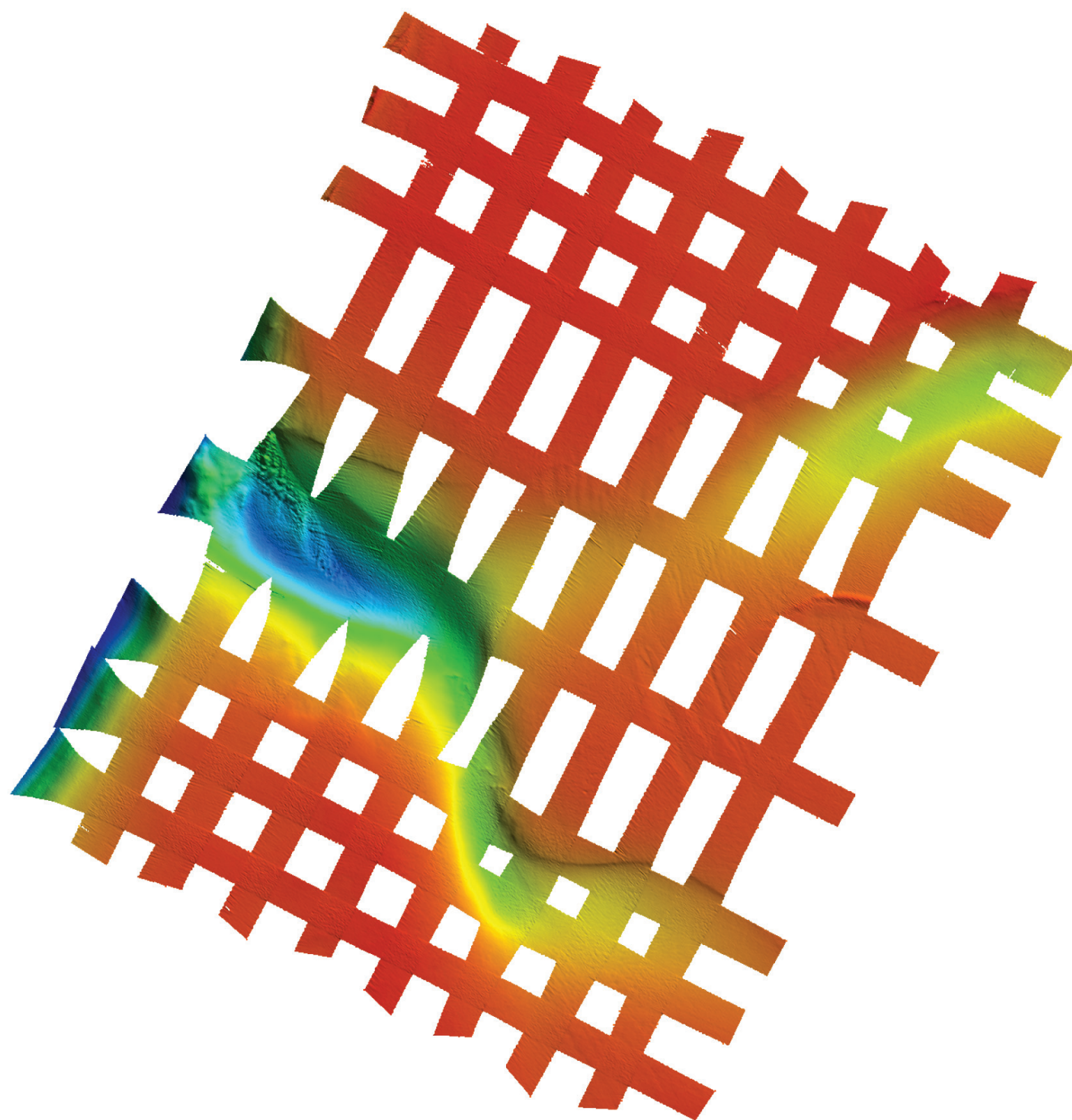


Figure 5.4.9: Archaeology Area 2 — Multibeam image of seabed.

5.5 Geophysical Results — wrecks

5.5.1 Introduction

The resultant datasets from both the sidescan and multibeam investigation were visualised within ArcGIS.

No convincing correlations were observed between the magnetometry data and the sidescan or multibeam sonar. The conclusion of this evaluation was that there was no significance to the magnetometer data within the survey areas.

A total of 126 anomalies were initially identified from the sidescan survey. Further assessment suggested that 17 of these had a high archaeological potential.

A further 25 anomalies were interpreted as having a medium archaeological potential, and 30 as having a low archaeological potential. The other anomalies were identified as geology, noise or pipelines.

A total of 146 anomalies were initially identified from the multibeam survey. Further assessment suggested that 15 of these had a high archaeological potential on the basis of their morphology.

Another 12 anomalies were interpreted as having a medium archaeological potential due to their morphology, and 20 as having a low archaeological potential. All the other anomalies were identified as geology, noise or pipelines.

5.5.2 Results

To ensure correlation between the known UKHO dataset and features identified from the sidescan sonar and multibeam bathymetry surveys, all new features identified with a HIGH or MEDIUM archaeological interpretation in either dataset were given a unique BA number, 1000 to 1061 (Table 5.5.1). The features identified as HIGH archaeological potential on either dataset are represented in Figures 5.5.1 to 5.5.25, with the remainder presented in Table 5.5.2.

Only three of these previously identified wrecks had any information recorded about them in the UKHO dataset beyond the survey information. The oldest wreck potentially identified (BA 1004) was the *Edmund Denison*, a 19th century wooden smack that was recorded wrecked in 1879. However, the UKHO record also states that this is a dead wreck, and so the correspondence

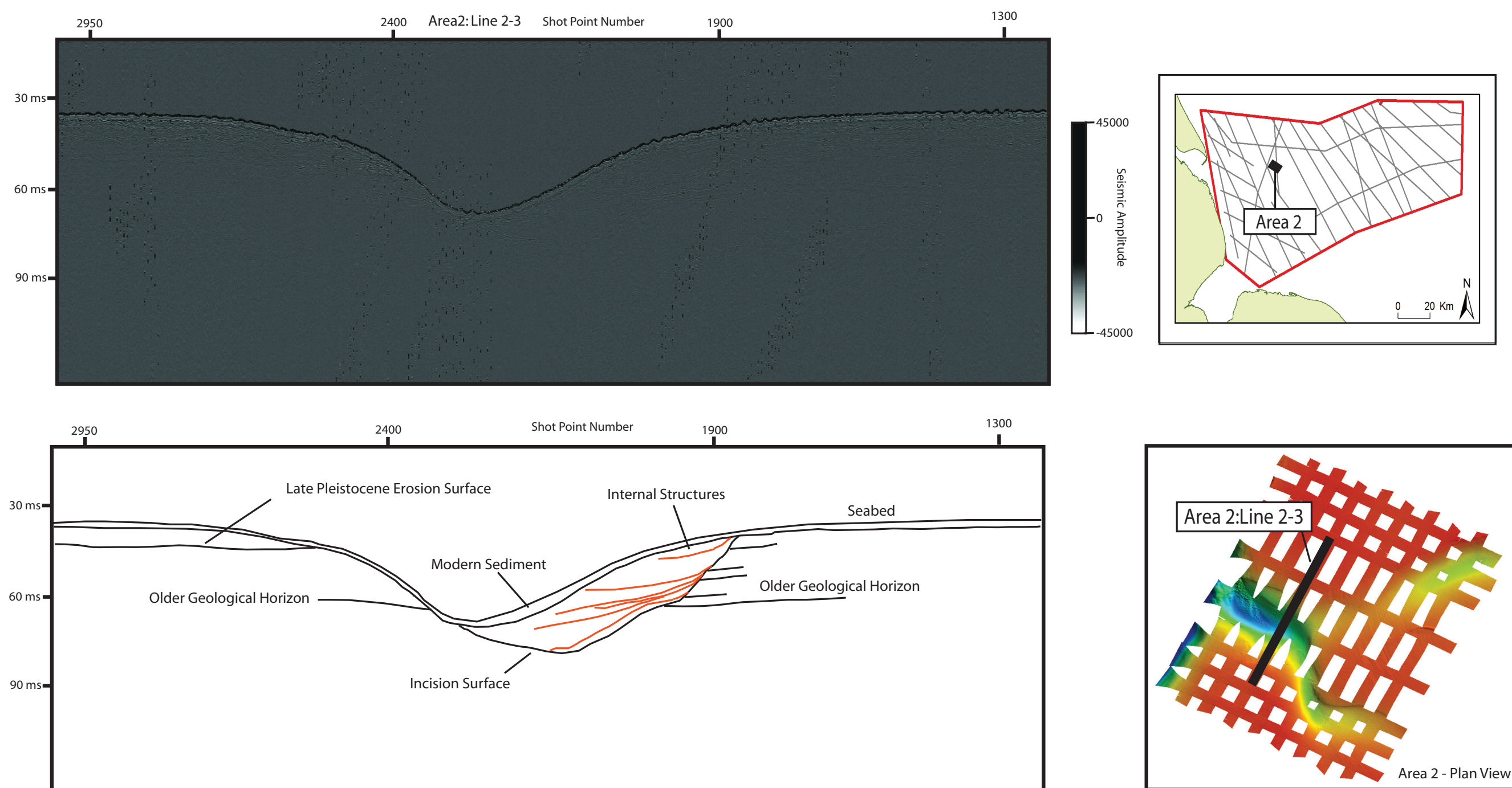


Figure 5.4.10: Seismic profile through the main channel system in Area 2. Internal structures can be clearly discerned.

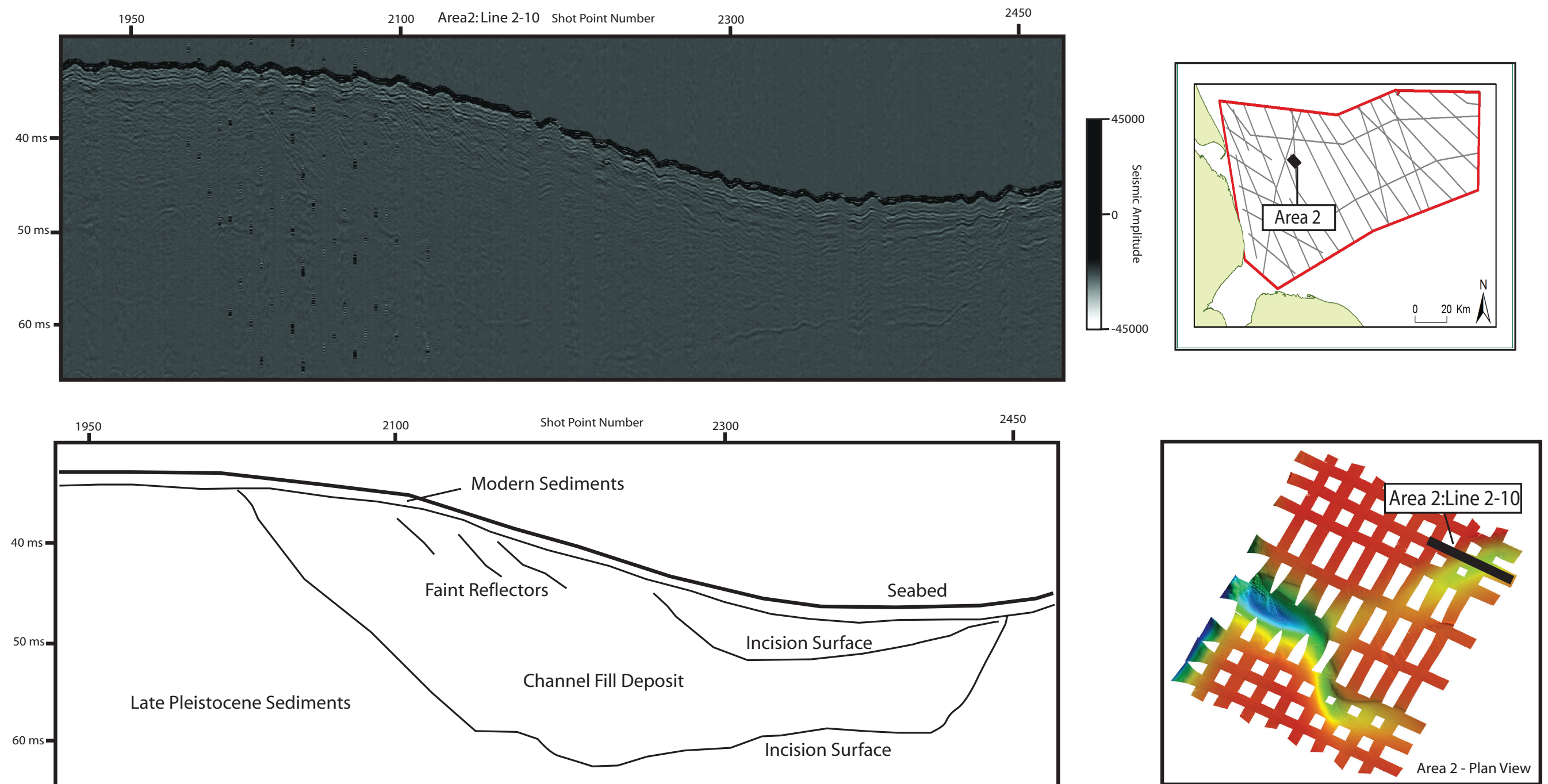


Figure 5.4.11: Seismic profile through an infilled channel system located to the east of the main channel. Internal features cannot be easily resolved.

BAno	Figure No	Sidescan Sonar/ Multibeam	UKHO number	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry Archaeological Interpretation
BA 1000	5.5.1	SM	UKHO 8672–50 m	High	Medium
BA 1001	5.5.2	SM	UKHO 8891–100 m	High	High
BA 1002	5.5.3	SM	UKHO 9156–50 m	High	Low/pock/geo
BA 1003	5.5.4	SM	UKHO 9471–50 m	High	High
BA 1004	5.5.5	SM	UKHO 8801–100 m	High	Medium
BA 1005	5.5.6	S	UKHO 8826–50 m	High	N/A
BA 1006	5.5.7	SM	UKHO 8872 –100 m	High	High
BA 1007	5.5.8	S	UKHO 8885–50 m	High	N/A
BA 1008	5.5.9	S	UKHO 9421–50 m	High	N/A
BA 1009	5.5.10	S	UKHO 9461–100 m	High	N/A
BA 1010	5.5.11	SM	N/A	High	Low
BA 1011	5.5.12	SM	N/A	High	Geological
BA 1012	5.5.13	SM	N/A	High	High
BA 1013	5.5.14	SM	N/A	Pipe	High
BA 1014	5.5.15	SM	N/A	Low	High
BA 1015	5.5.16	SM	N/A	Low–medium	High
BA 1016	5.5.17	SM	N/A	High	High
BA 1017	5.5.18	S	N/A	High	N/A
BA 1018	5.5.19	SM	N/A	Low–medium	High
BA 1019	5.5.20	SM	N/A	Medium	High
BA 1023	5.5.21	SM	N/A	High	High
BA 1058	5.5.22	M	N/A	N/A	High
BA 1059	5.5.23	M	N/A	N/A	High
BA 1060	5.5.24	S	N/A	High/geology	N/A
BA 1061	5.5.25	M	N/A	N/A	High

Table 5.5.1: Features identified in the sidescan sonar and multibeam bathymetry surveys with a HIGH archaeological potential.

with the feature identified in the same area on the sidescan sonar dataset may be coincidental. The other two wrecks were of 20th century date. The *Katina Bulgaris* was a Greek steel built steamship *en route* from Hull to Buenos Aires when she was lost in a collision in 1939. The *HMS Cape Spartel* was a steel fishing trawler hired by the Admiralty in 1939, and was on minesweeping duty around the Outer Dowsing Shoal in 1942 when she was

attacked and bombed by German aircraft. As she was in the employ of the Admiralty at the time of sinking, the wreck is eligible for designation under the PMRA 1986.

Figure 5.5.1: Wreck BA 1000

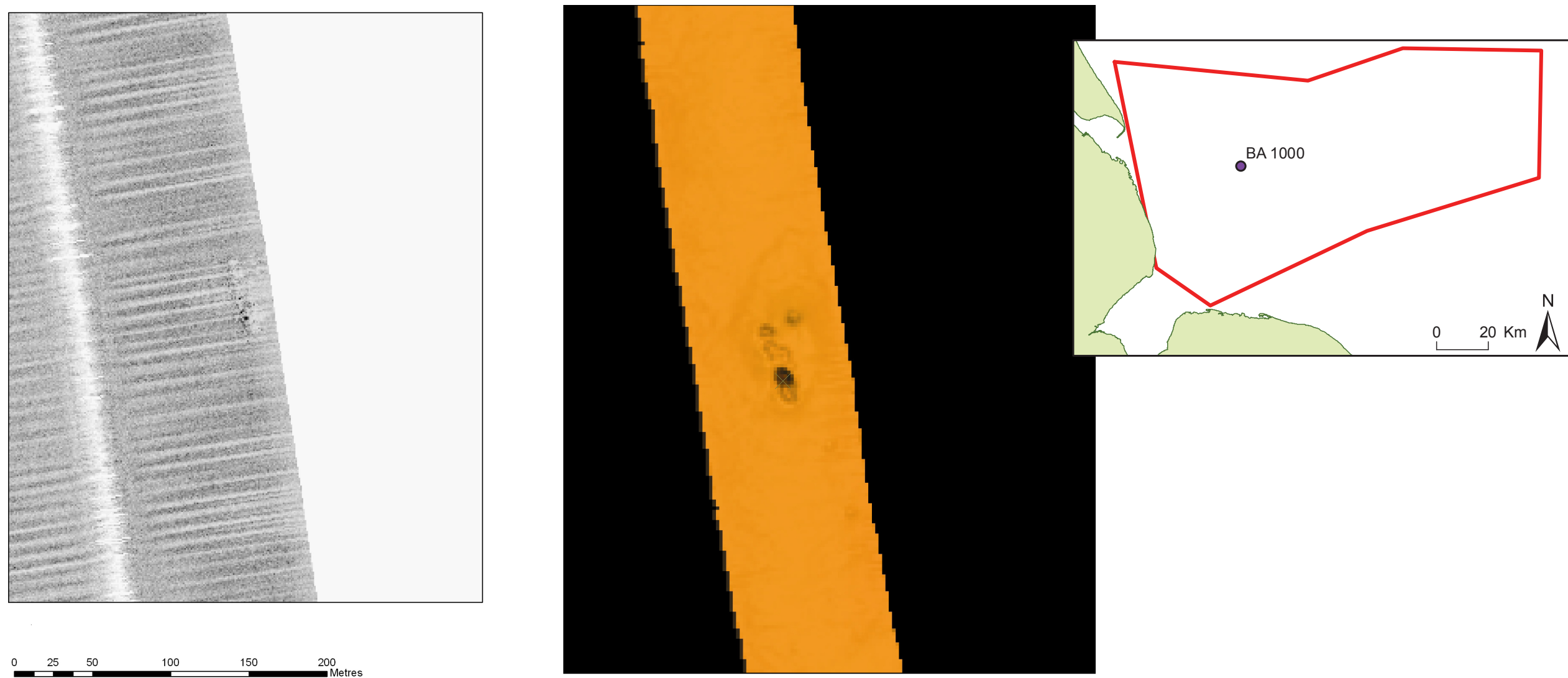


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.1	BA 1000	SM	UKHO 8672 - 50m	<p>'The <i>HMS Cape Spartel</i> was a steel fishing trawler, built in 1929 by Cochrane and Sons Ltd, Selby and originally owned by the Hudson Steam Fishing Co. Ltd. She was hired as a minesweeper by the Admiralty in 1939. She was on minesweeping duty around the Outer Dowsing Shoal in 1942 when she was attacked and bombed by German aircraft. There is no mention of the fate of the crew (Young 2004). Young records that the wreck is dispersed, standing some 4.2m high around midships, and has been swept by wires (Young, 2004). <i>The Shipwreck Index of the British Isles</i> makes no mention of the minesweeping, recording she was still with her previous owners (Larn and Larn 1997). As she was in the employ of the Admiralty at the time of the sinking, the wreck is eligible for designation under the PMRA 1986.</p> <p>The UKHO record this wreck with sonar dimensions of 64 m x 16 m with a shadow height of 4.2 and orientated at 160 degrees. The vessel is recorded as having a gross tonnage of 346. The wreck is described as well broken up.'</p>	S93	Possible feature, N S, 54 m x 15 m	High	M106	Possible feature	Medium		356481.7156	5928599.281

Figure 5.5.2: Wreck BA 1001

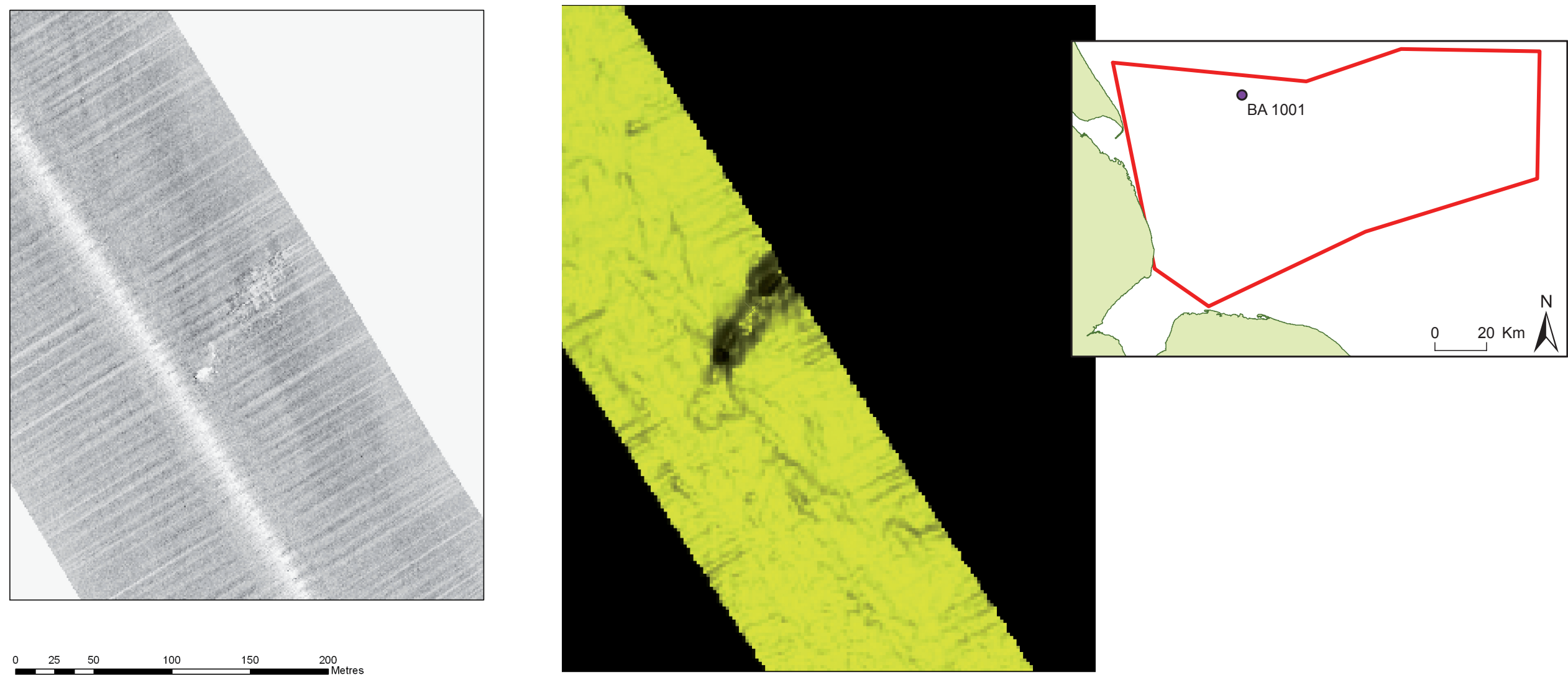


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.2	BA 1001	SM	UKHO 8891 - 100 m	The UKHO record this wreck as having a sonar length of 60 m and a shadow height of 7.3 m, at an orientation of 30 degrees. The date sunk is not recorded, however she was originally detected in 1941. The wreck is described as upright and intact, with the east end buried.	S34	Feature, NE SW, 110 m x 30 m max	High	M68	Upright feature aligned NE SW	High		357535.878	5956350.204

Figure 5.5.3: Wreck BA 1002

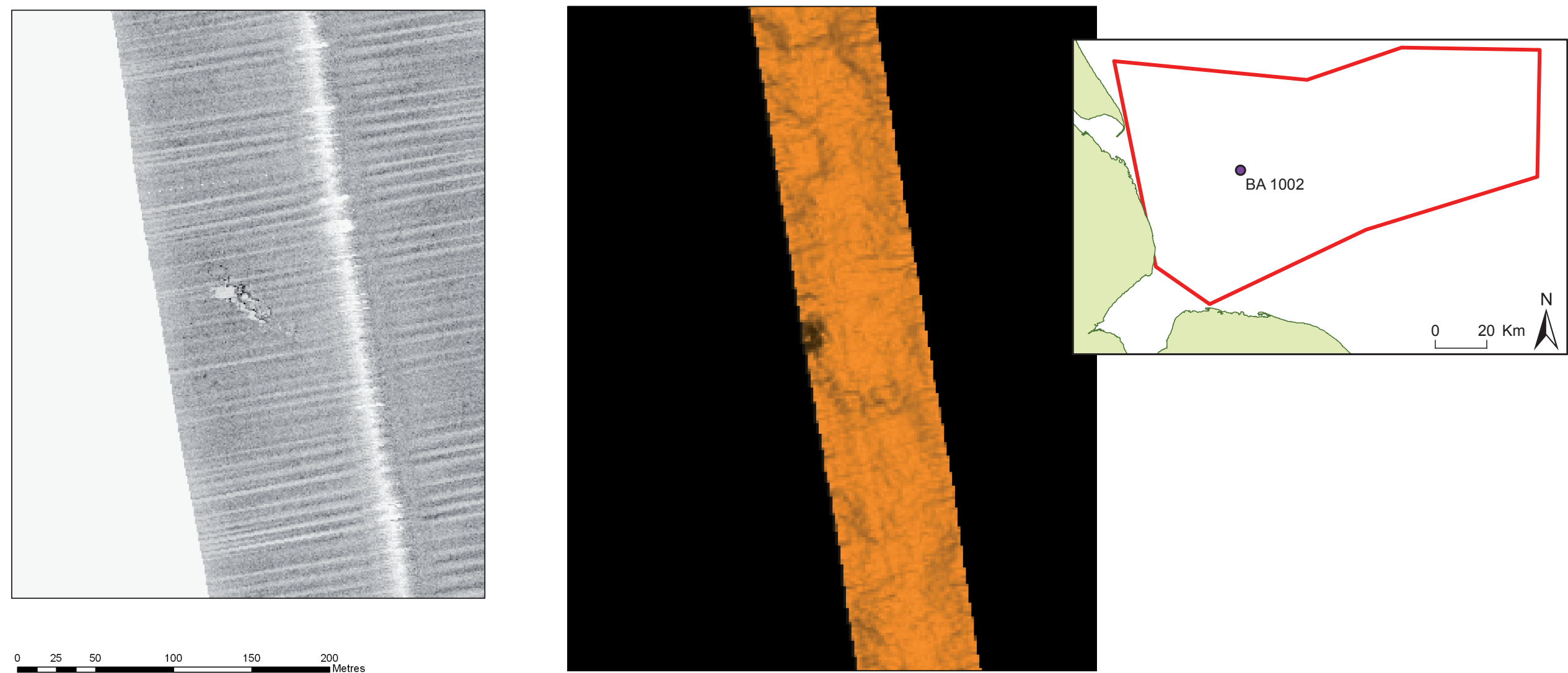


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.3	BA 1002	SM	UKHO 9156 - 50 m	The UKHO record this wreck as having sonar dimensions of 58 m x 2.7 m with a shadow height of 2.7 m at an orientation of 125 degrees. The date sunk is not recorded, however, she was originally detected in 1993. The wreck is described as well defined and partly buried	S94	Feature, NW SE, 65 m x 15 m	High	M108	Possible feature at edge of scan	Low/pock/geo		356609.6087	5926639.546

Figure 5.5.4: Wreck BA 1003

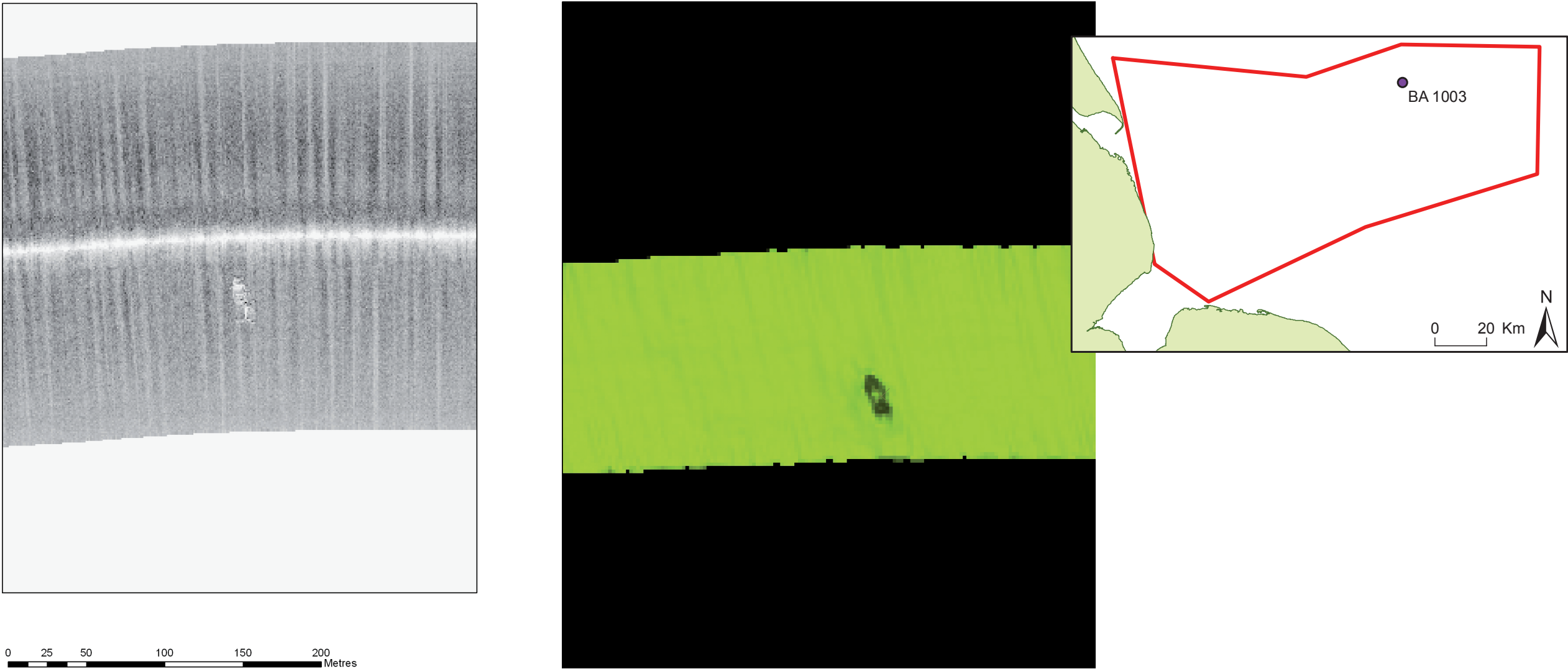


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.4	BA 1003	SM	UKHO 9471 - 50 m	The UKHO record this wreck as having sonar dimensions of 36 m x 8 m with a shadow height of 23.6 m at an orientation of 144 degrees. The date sunk is not recorded, however she was originally detected in 1989.	S68	Feature, N S, 32 m x 10 m	High	M38	Upright feature aligned roughly N S	High	M112	419614.2179	5959492.813

Figure 5.5.5: Wreck BA 1004

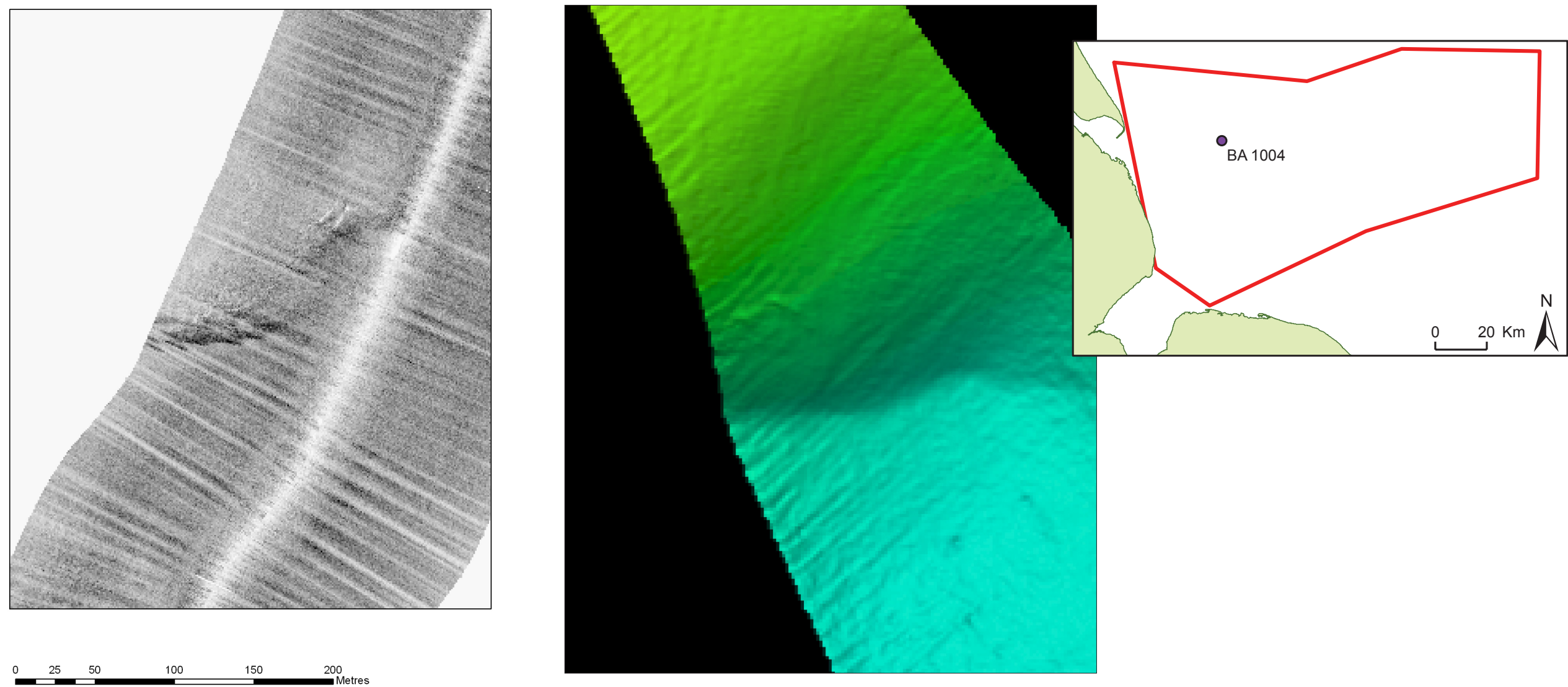


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.5	BA 1004	SM	UKHO 8801 - 100 m	The UKHO record this wreck as the <i>Edmund Denison</i> , a wooden British Smack. The wreck on these records is described as dead, and has no sonar information. She had a gross tonnage of 50, and a cargo of ballast when she sunk in 1879. She was on route from Grimsby to fishing grounds when she was in collision with the sailing vessel <i>Leader</i> . No mention is made of the fate of the crew (Larn and Larn 1997).	S45	Possible feature, E W, 55 m x 20 m	High	M127	Faint anomaly at edge of scan	Medium		349426.6276	5938520.427

Figure 5.5.6: Wreck BA 1005

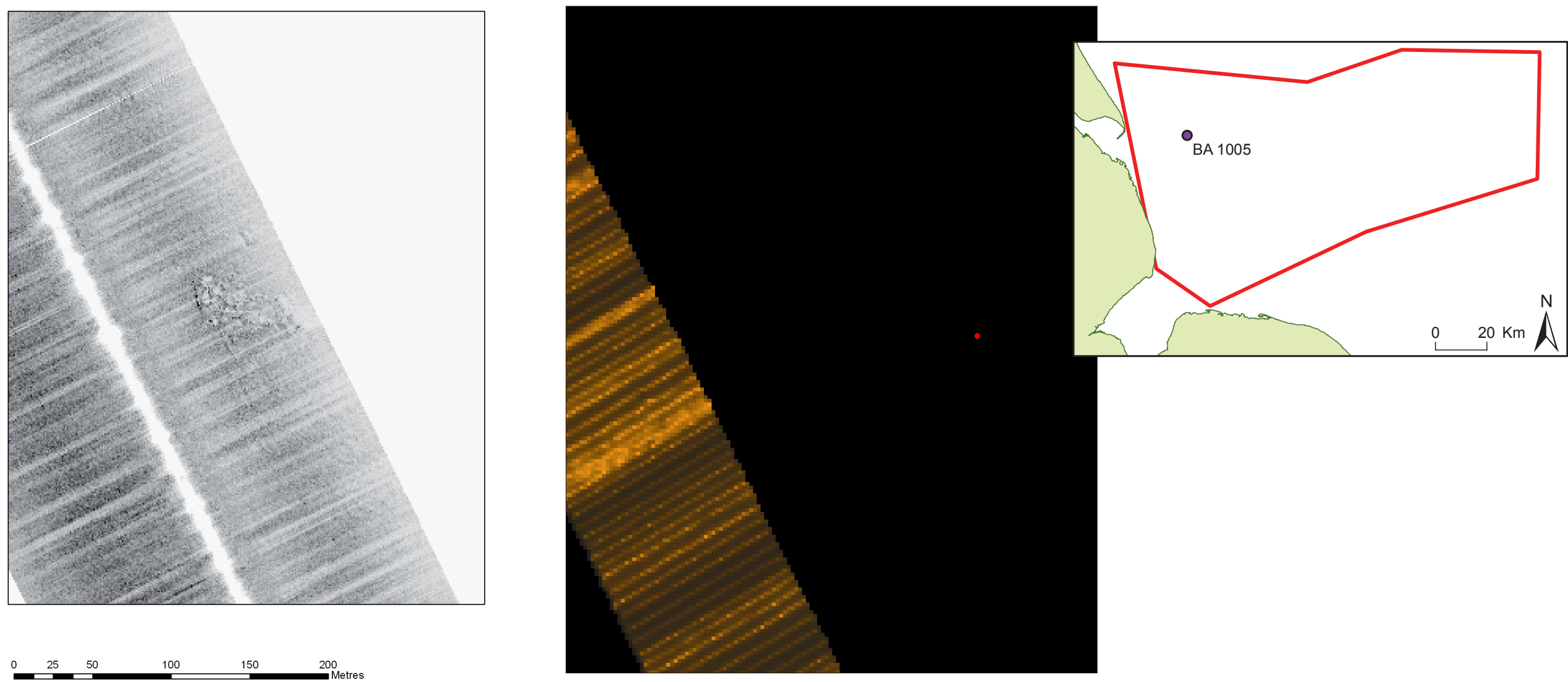


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.6	BA 1005	S	UKHO 8826 - 50 m	'The <i>Katina Bulgari(s)</i> was a Greek steel steamship <i>en route</i> from Hull to Buenos Aires in 1939 when she was lost following a collision with the USA steamer Meanticut of New Orleans. The crew and passengers survived the incident (Larn and Larn 1997). Young reports that the wreck was a navigational hazard and as such has been systematically dispersed over the years. She covers an area of seabed measuring 132 m by 21 m with fair sized lumps of non-ferrous metal seen in the mounds of debris (Young, 2004, 171).	S45	Possible feature, E W, 55 m x 20 m	High	M127	Faint anomaly at edge of scan	Medium		349426.6276	5938520.427

Figure 5.5.7: Wreck BA 1006

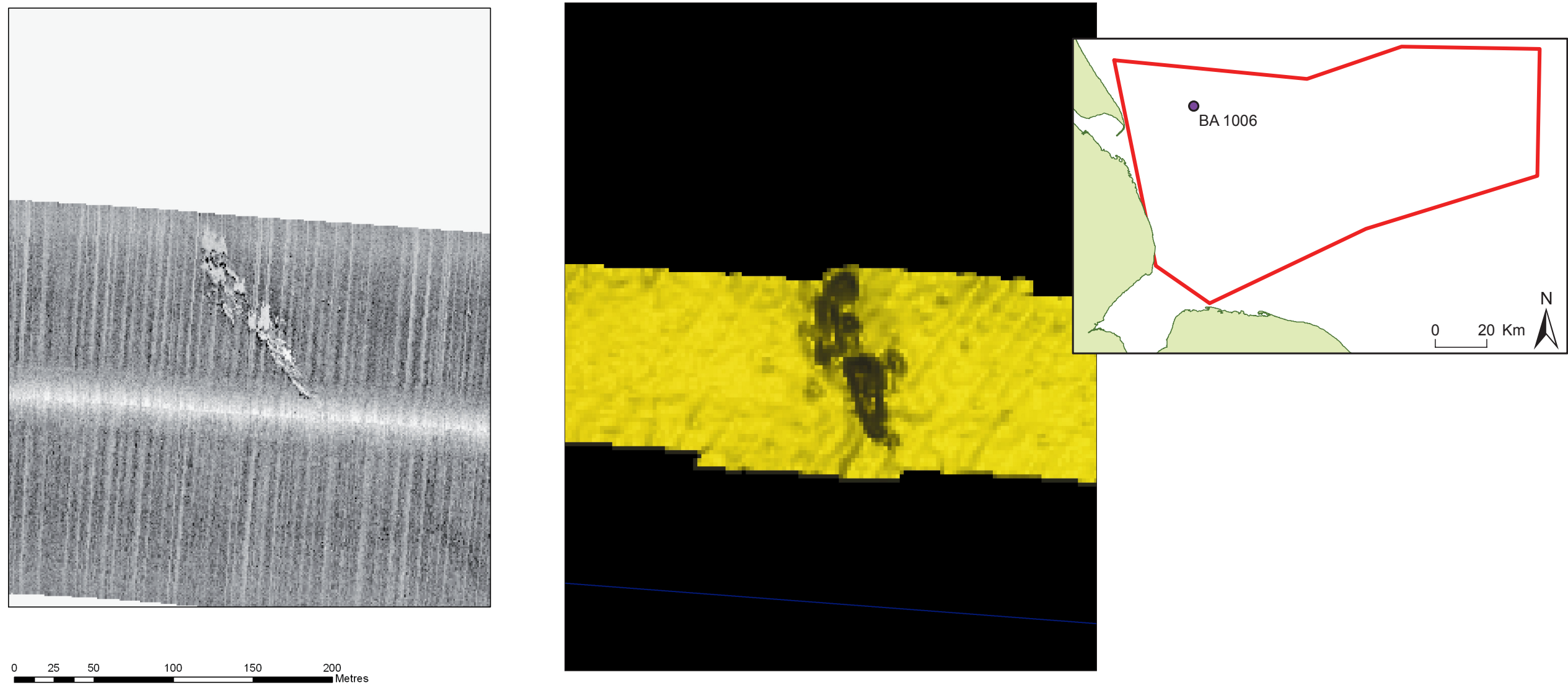


Figure No	BAno	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.7	BA 1006	SM	UKHO 8872 - 100 m	The UKHO record this wreck as having sonar dimensions of 87 m x 19 m with a shadow height of 5.7 m at an orientation of 158 degrees. The date sunk is not recorded, however she was originally detected in 1945, and the wreck is described as intact.	S73	Large feature, NW SE, 125 m x 27 m	High	M128	Large feature aligned roughly NS	High		338568.7781	5951060.08

Figure 5.5.8: Wreck BA 1007

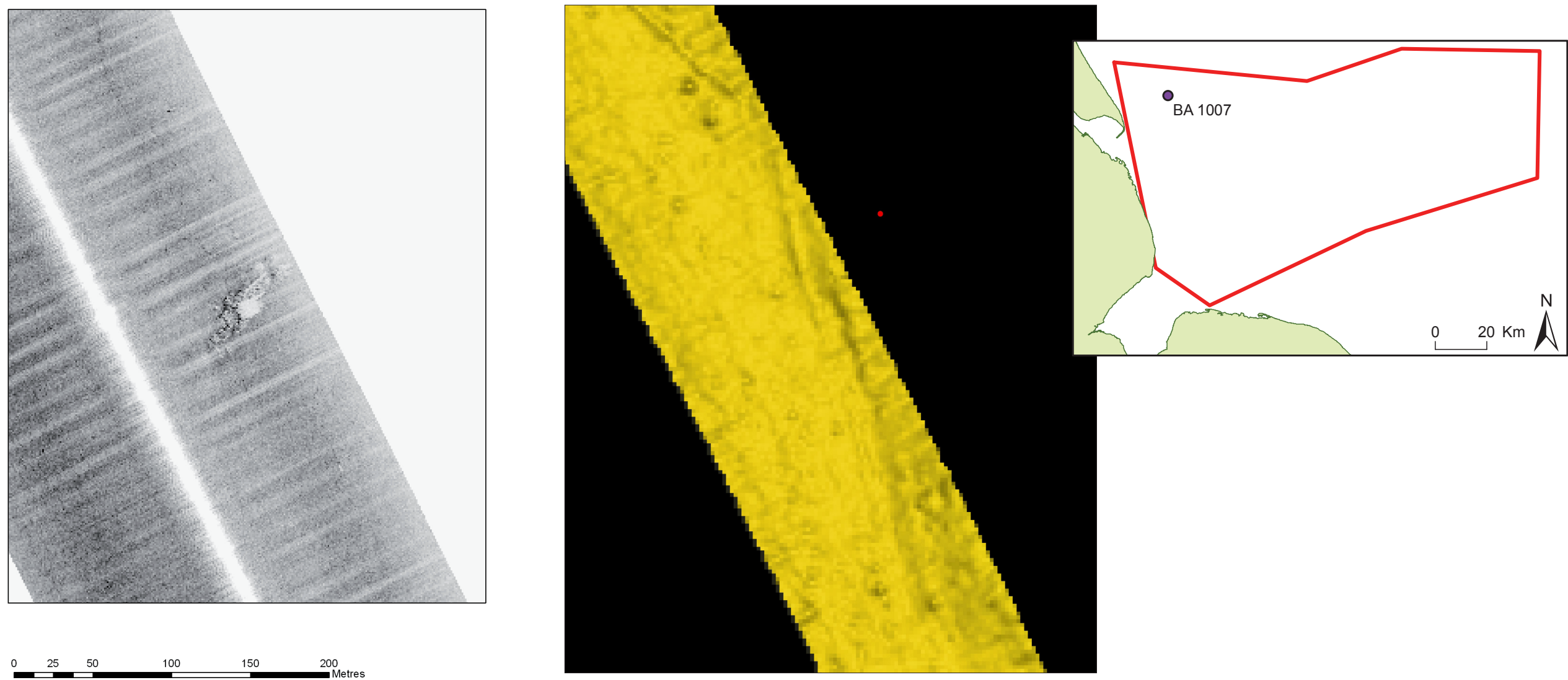


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.8	BA 1007	S	UKHO 8885 - 50 m	The UKHO record this wreck as having a sonar length of 45.7 m and a shadow height of 4.4 m, at an orientation of 45 degrees. The date sunk is not recorded, however she was originally detected in 1944. The wreck is described as having the engine and boiler as high points, with the rest collapsed.	S67	Feature, NE SW, 70 m x 23 m	High	N/A	Not on Multibeam	N/A		328546.9446	5956003.97

Figure 5.5.9: Wreck BA 1008

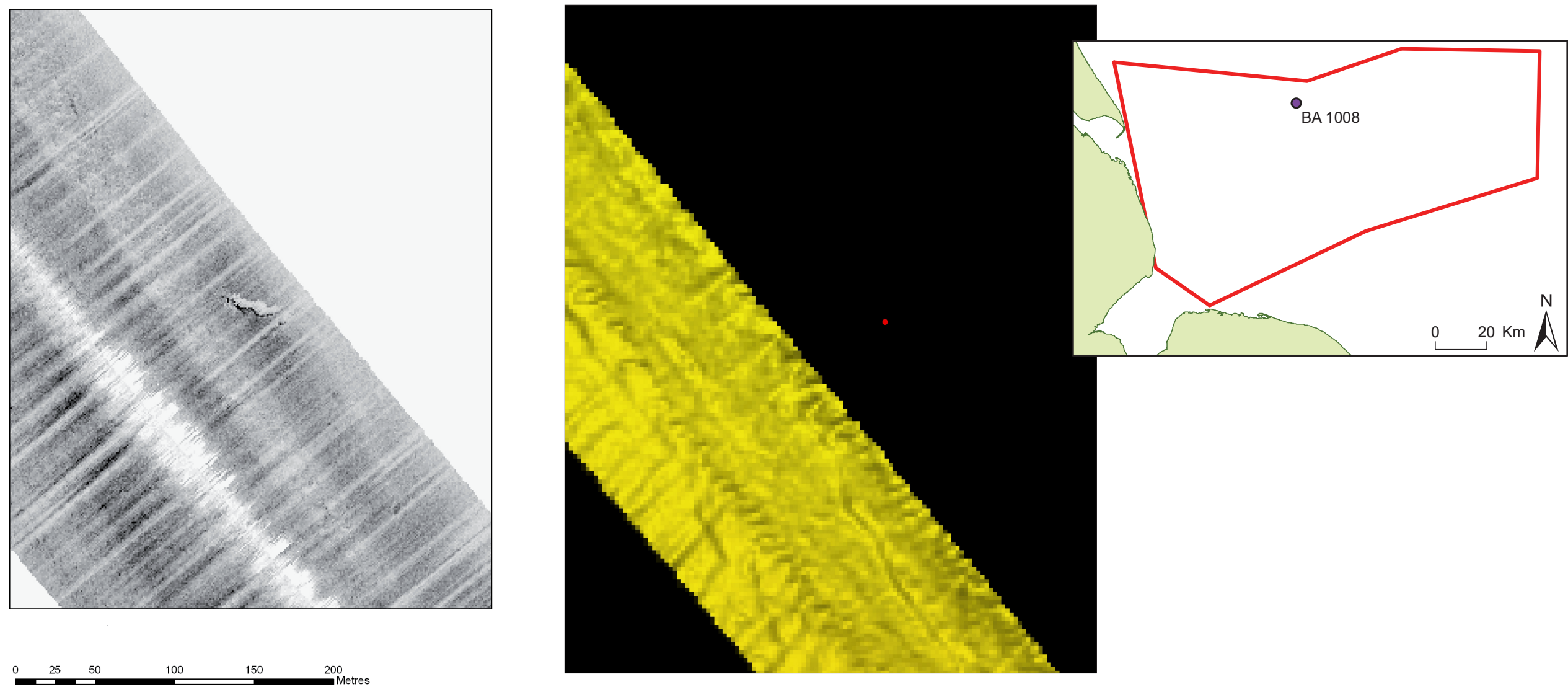


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.9	BA 1008	S	UKHO 9421 - 50 m	The UKHO record this wreck as having sonar dimensions of 15 m x 5 m with a shadow height of 2.5 m at an orientaion of 95 degrees. The date sunk is not recorded, however she was originally detected in 1987.	S5	Feature, E W, 30 m x 8 m	High	N/A	Not on Multibeam	N/A	S10	378183.3866	5953077.371

Figure 5.5.10: Wreck BA 1009

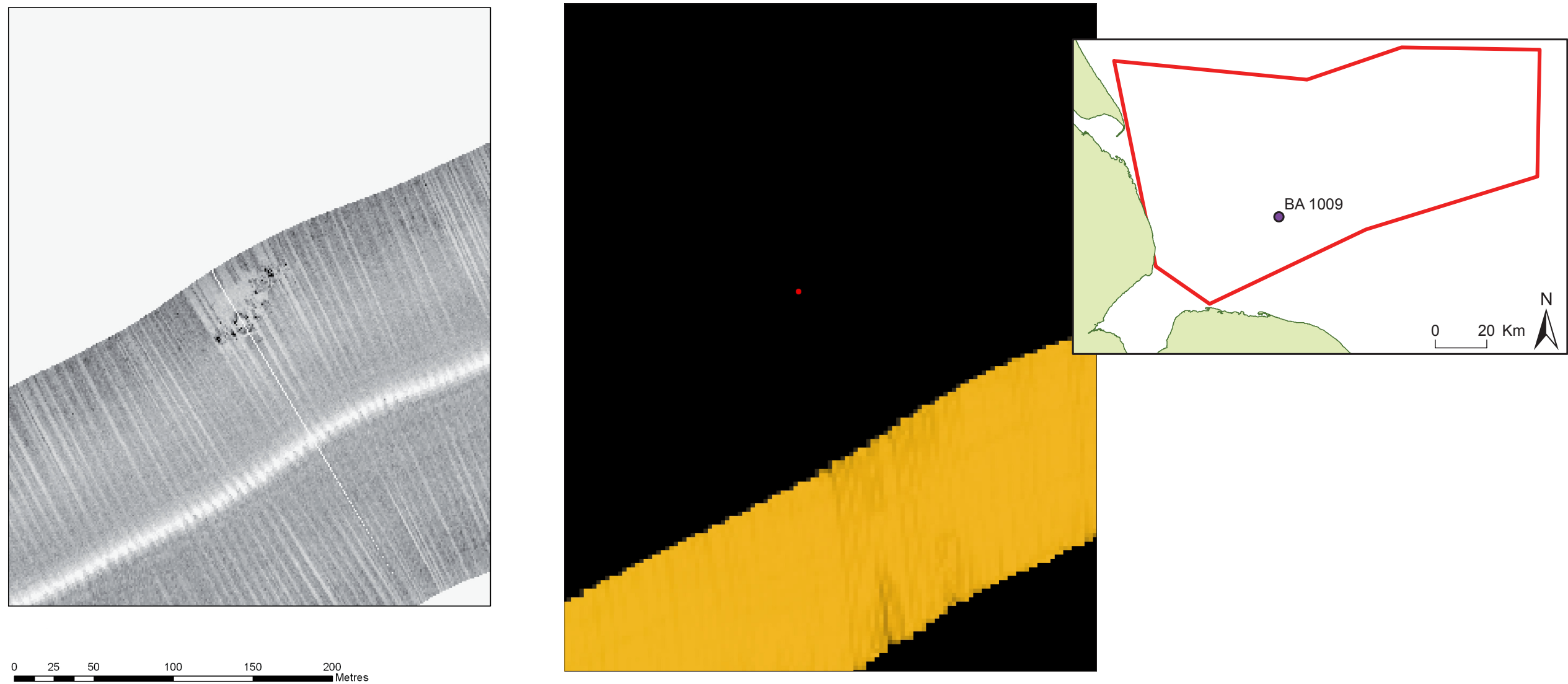


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.10	BA 1009	S	UKHO 9461 - 100 m	The UKHO record this wreck as having sonar dimensions of 85 m x 25 m with a shadow height of 5.7 m at an orientation of 45 degrees. The date sunk is not recorded, however the original detection date is 1990. The wreck is described as being in two parts, in line and overlapping.	S104	Feature, NE SW, 62 m x 18 m	High	N/A	Not on Multibeam	N/A		371625.4255	5908444.004

Figure 5.5.11: Wreck BA 1010

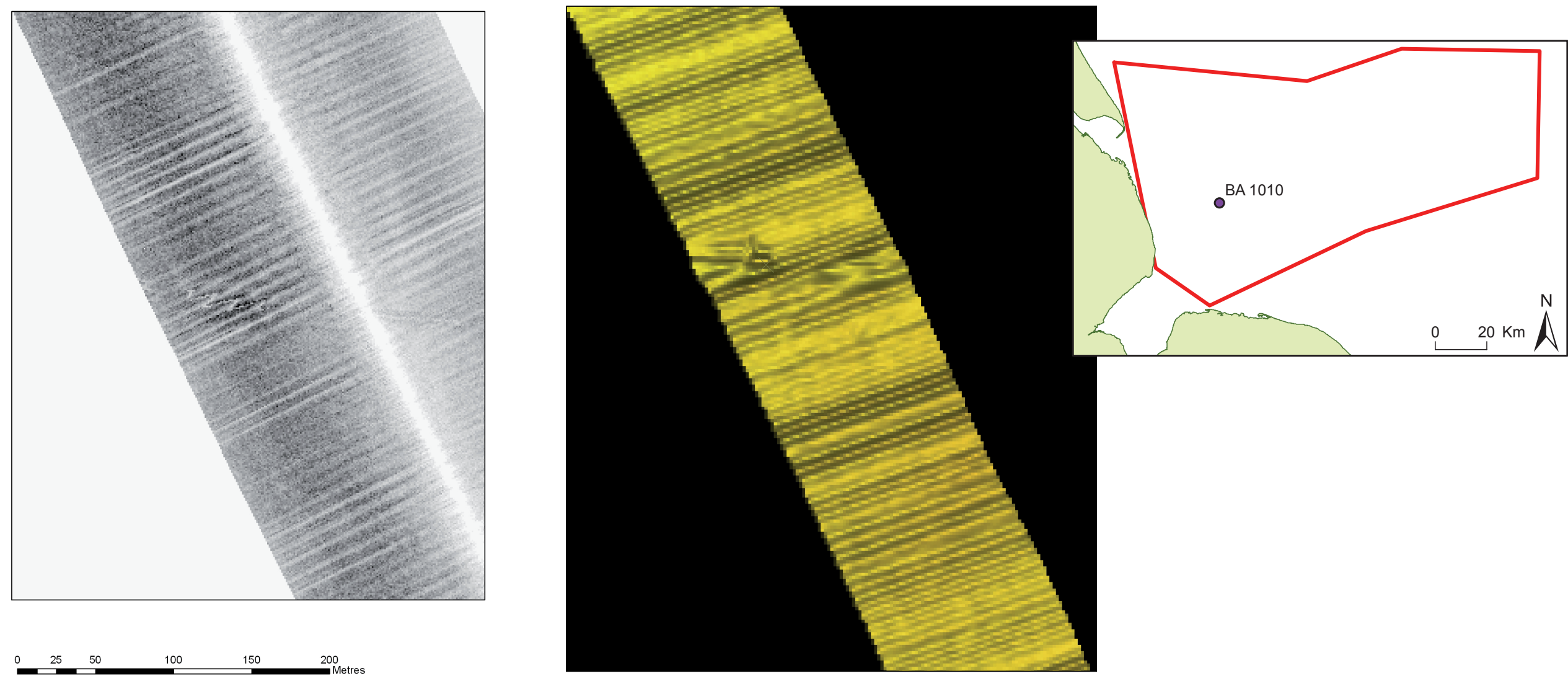


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.11	BA 1010	SM	N/A	Not on UKHO	S61	Possible feature or pipeline	High	M85	Possible feature	Low		348580.663	5914455.927

Figure 5.5.12: Wreck BA 1011

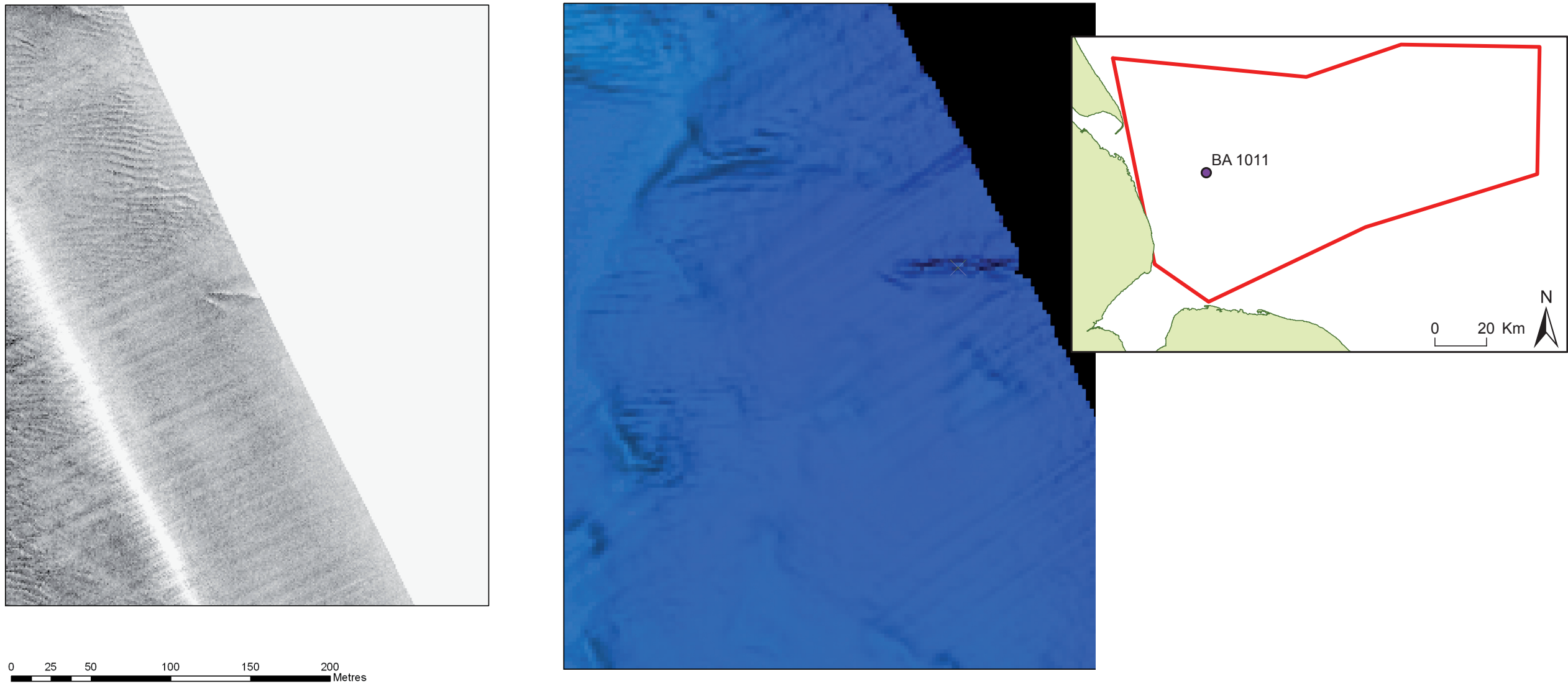
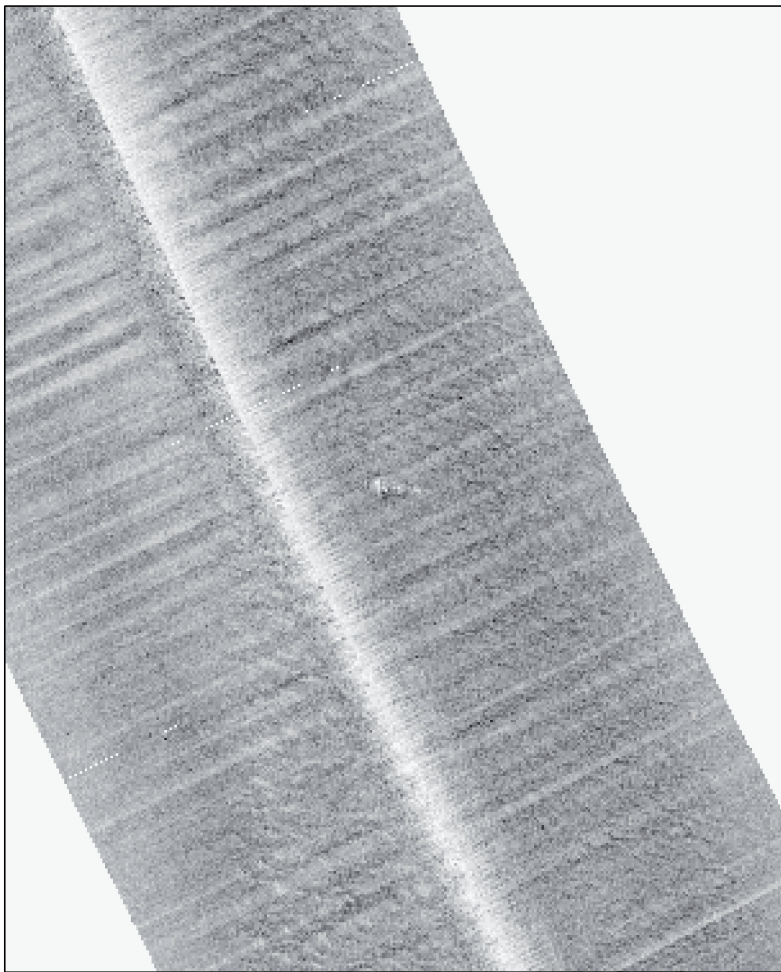


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.12	BA 1011	SM	N/A	Not on UKHO	S62	Possible feature, E W, approx 37 m x 25 m	High	M98	Possible feature	Geological		343883.8135	5924574.62

Figure 5.5.13: Wreck BA 1012



0 25 50 100 150 200 Metres

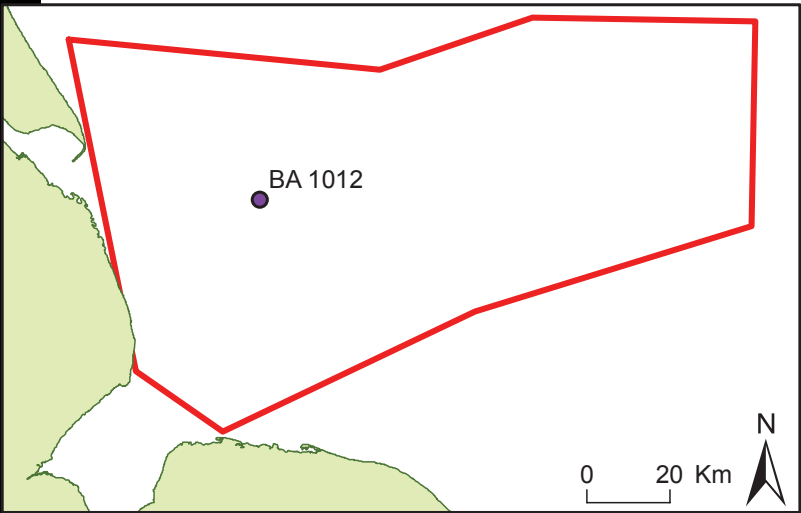
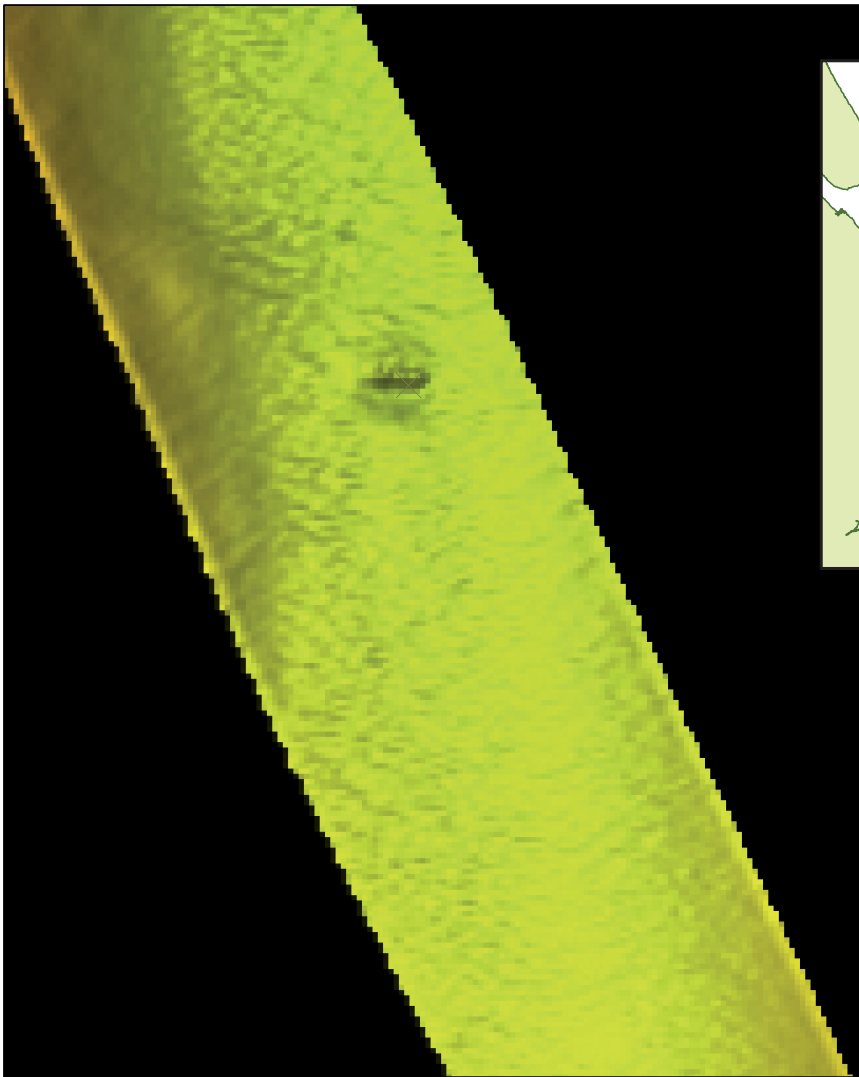


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.13	BA 1012	SM	N/A	Not on UKHO	S47	Feature, E W, 23 m x 8 m	High	M73	Possible feature	High	M78	353631.5952	5930354.946

Figure 5.5.14: Wreck BA 1013

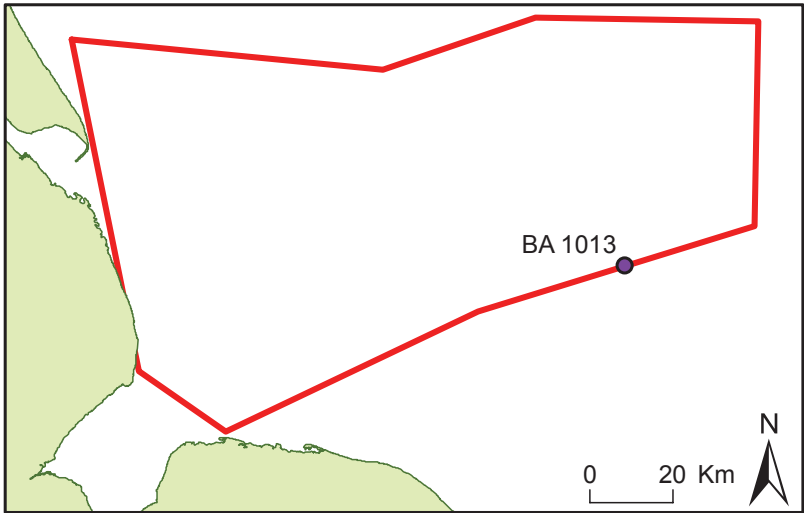
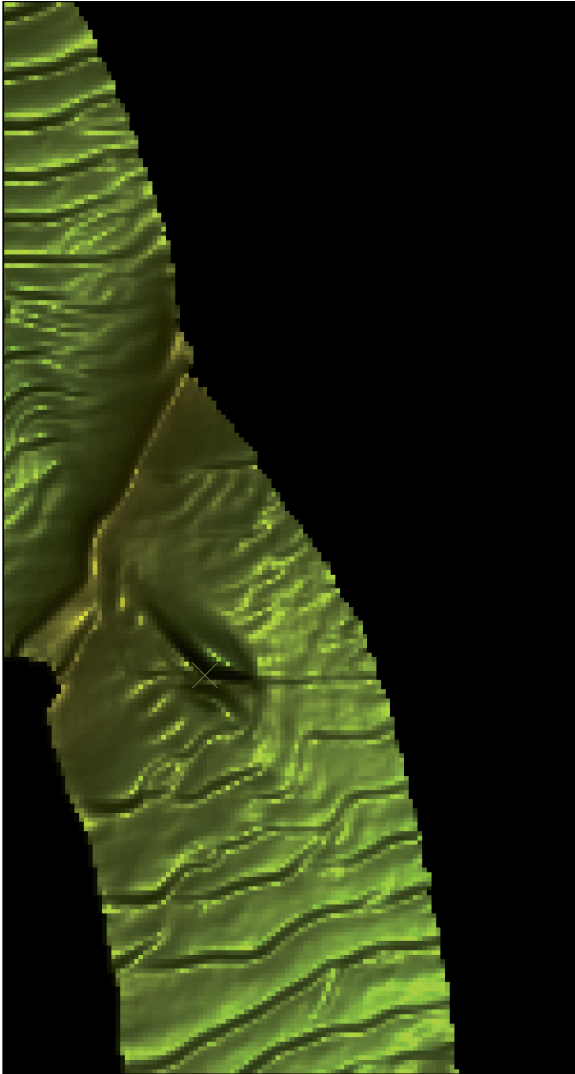
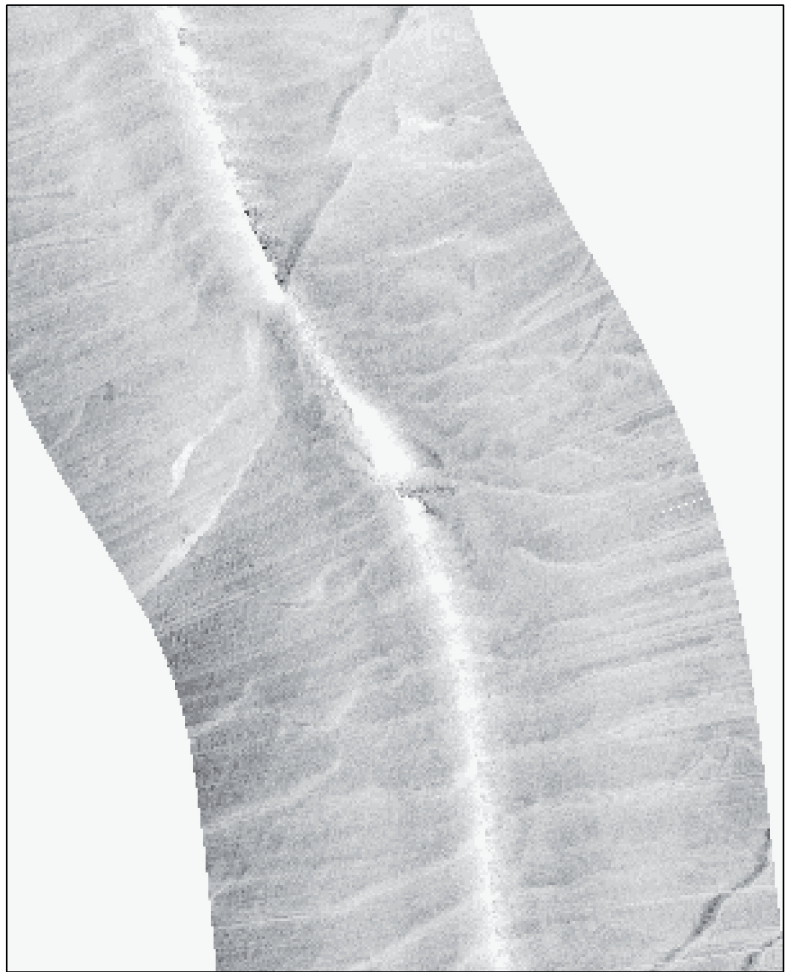


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.14	BA 1013	SM	N/A	Not on UKHO	S76	Possible feature, roughly NW SE, 90 m x 27 m	Pipe	M89	Possible feature	High		440299.7796	5914684.806

Figure 5.5.15: Wreck BA 1014

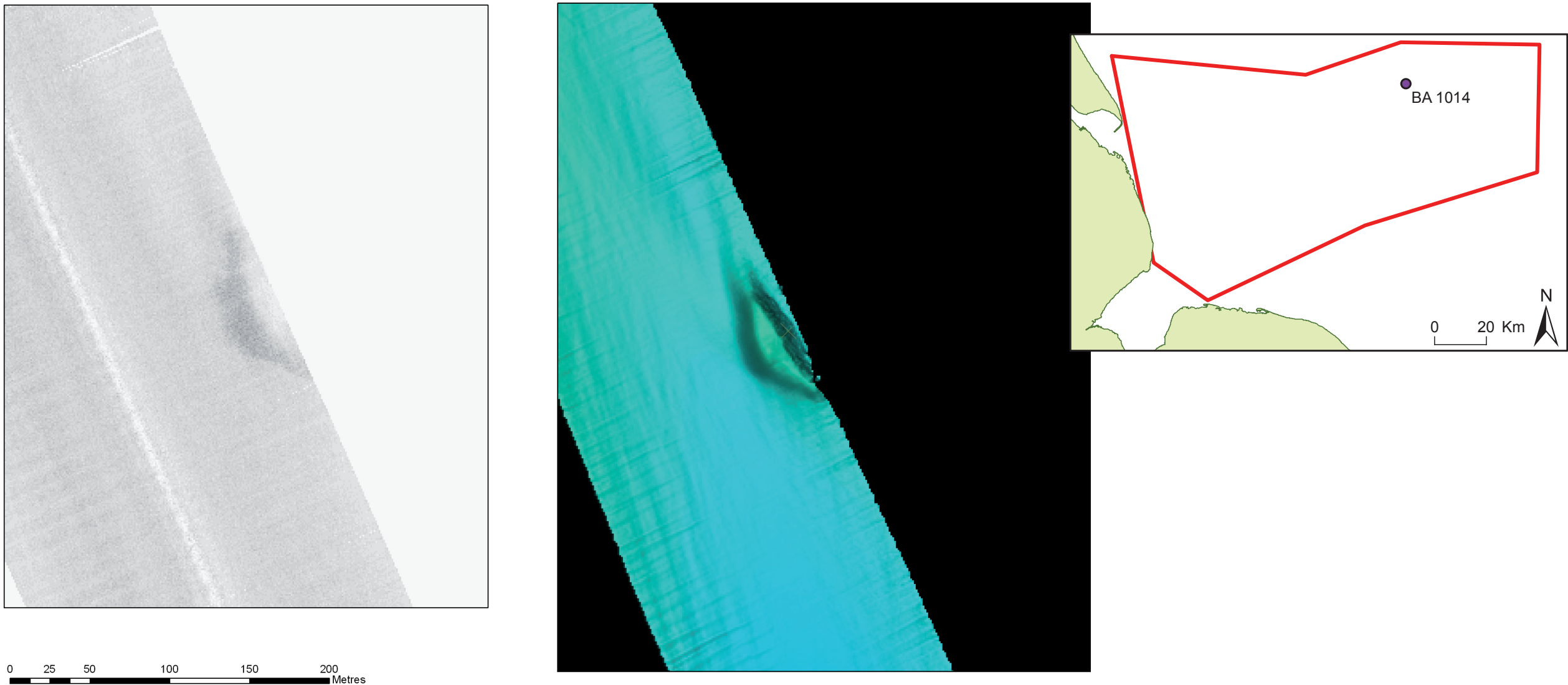


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.15	BA 1014	SM	N/A	Not on UKHO	S80	Possible feature, approx 105 m x 25 m	Low	M92	Possible feature	High		421085.2801	5958194.741

Figure 5.5.16: Wreck BA 1015

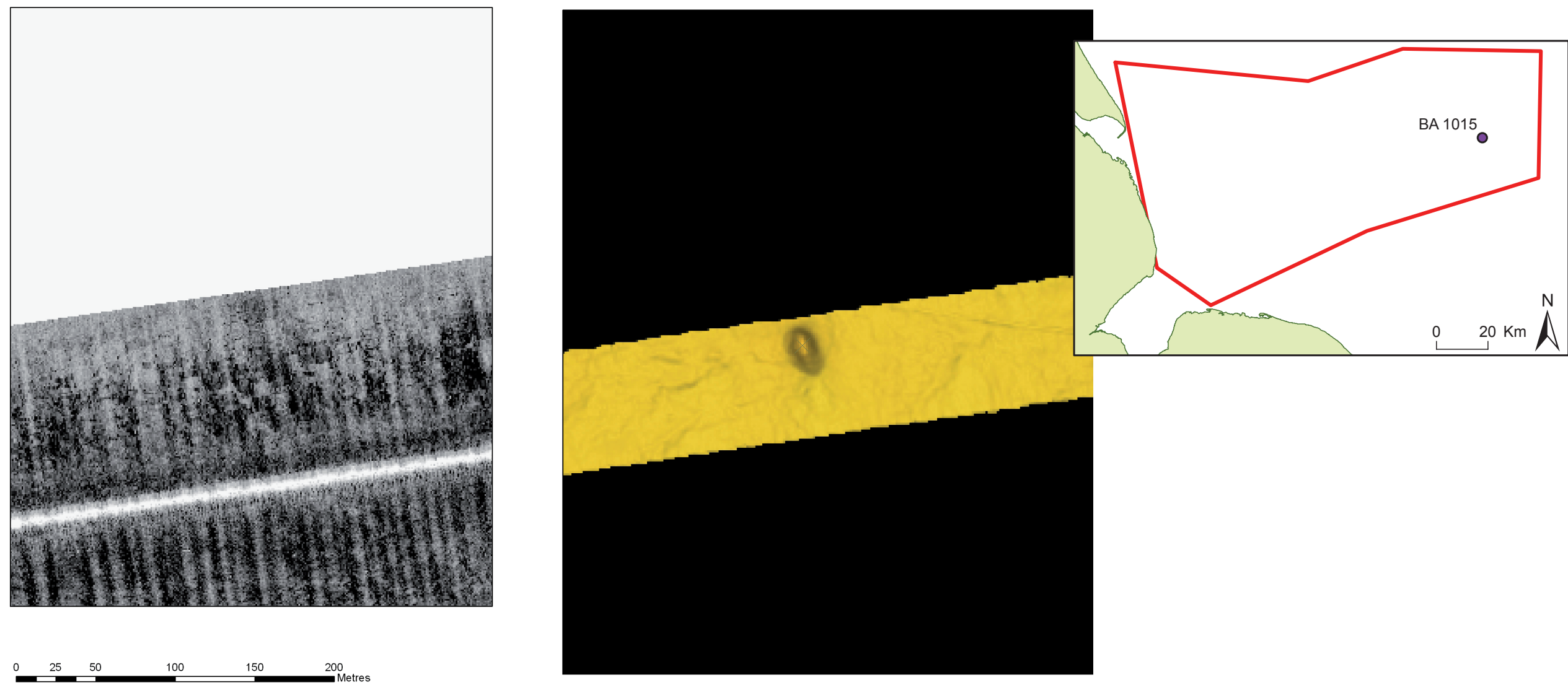
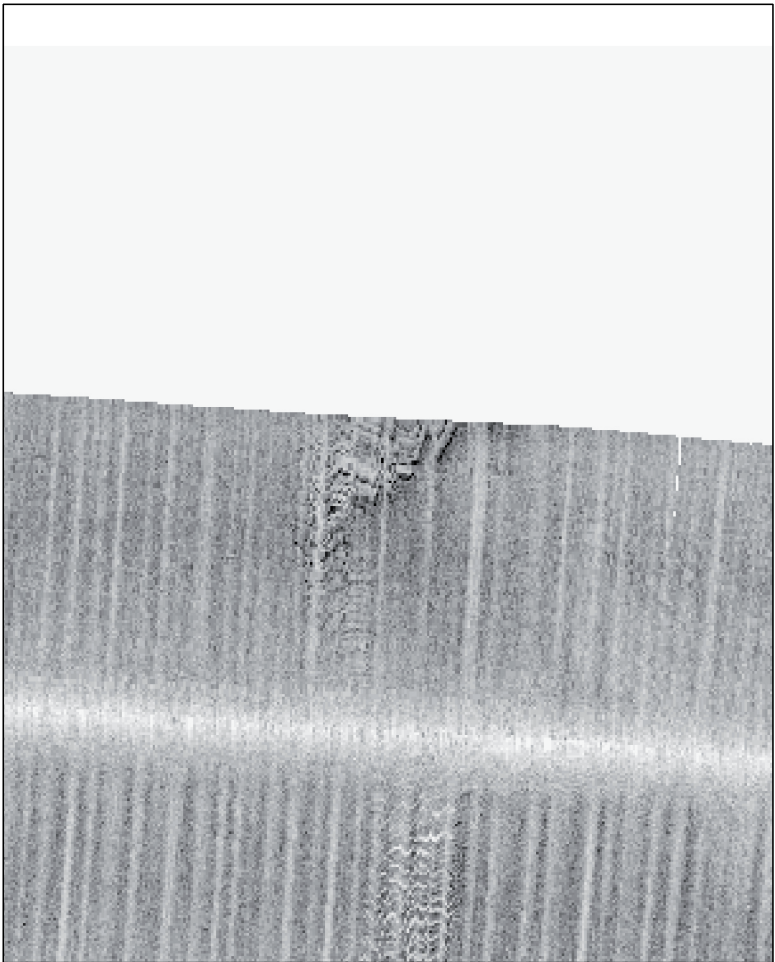


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.16	BA 1015	SM	N/A	Not on UKHO	S116	Possible feature, seen at edge of scan	Low-medium	M116	Upright feature aligned roughly NS	High		449736.6901	5939761.056

Figure 5.5.17: Wreck BA 1016



0 25 50 100 150 200 Metres

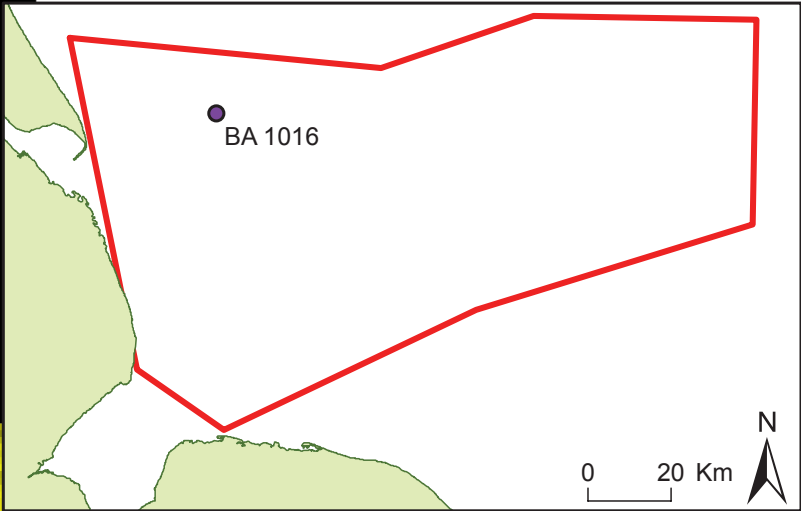
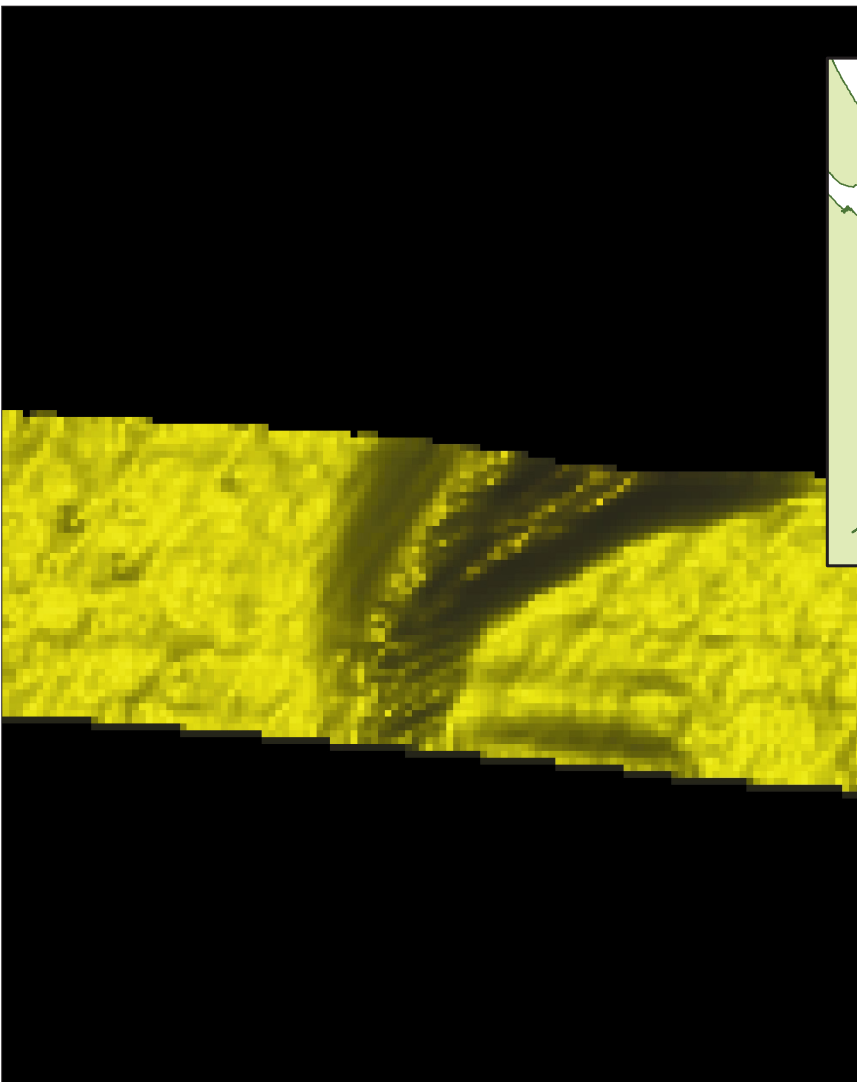


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.17	BA 1016	SM	N/A	Not on UKHO	S102	Large feature, roughly NE SW, 75 m x 45 m	High	M129	Large feature roughly NE SW	High		342858.2673	5950723.485

Figure 5.5.18: Wreck BA 1017

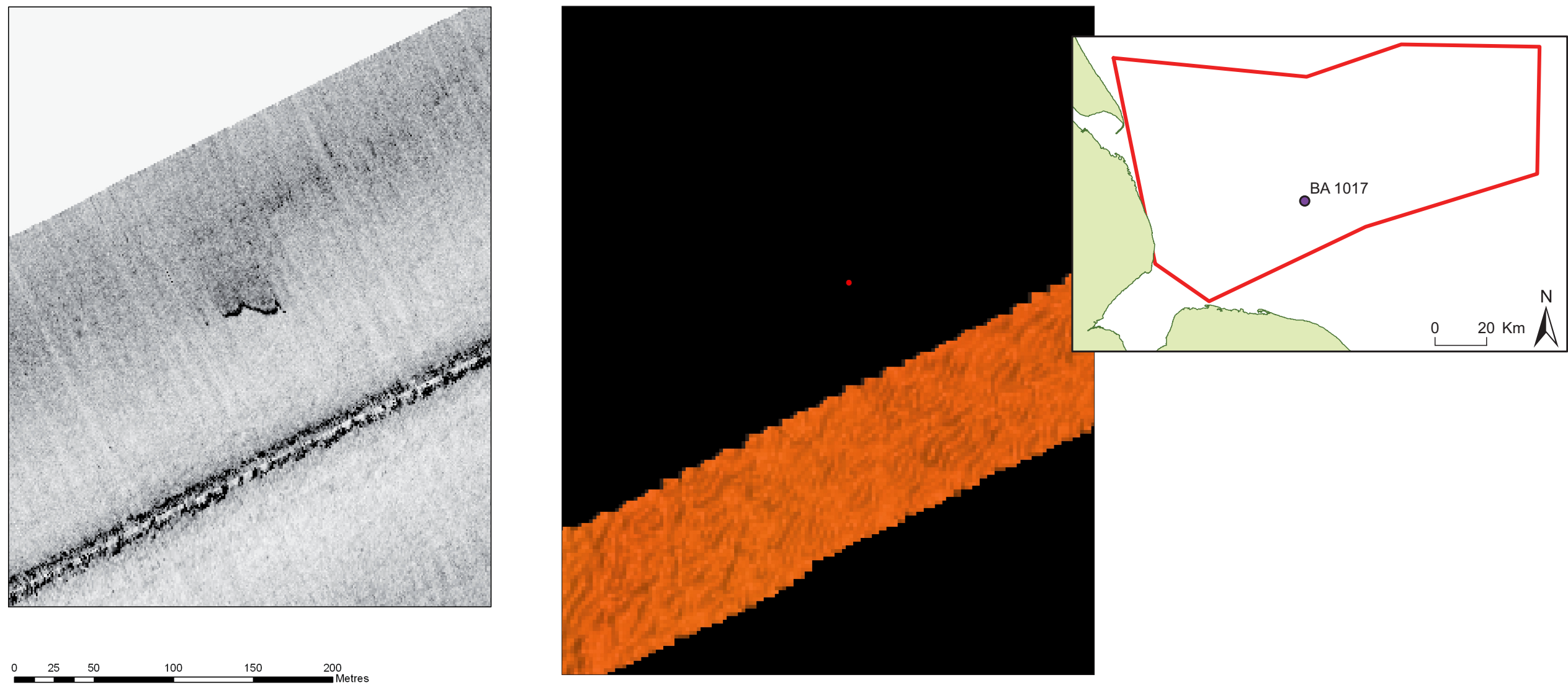


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.18	BA 1017	S	N/A	Not on UKHO	S109	Possible feature though most likely geological, E W, 38 m	High	N/A	Not on Multibeam	N/A		381619.7161	5913512.998

Figure 5.5.19: Wreck BA 1018

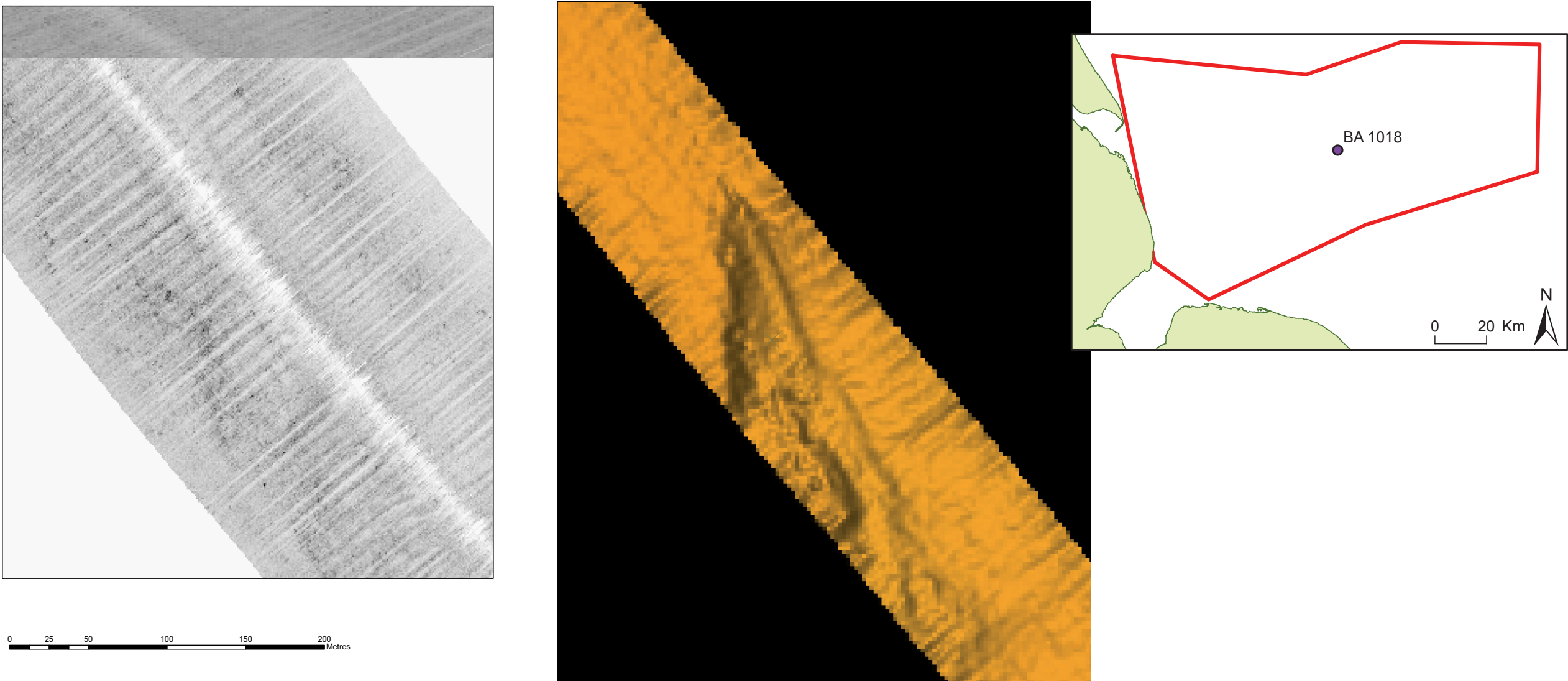


Figure No	BAno	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.19	BA 1018	SM	N/A	Not on UKHO	S121	Very faint anomaly	Low-medium	M59	large feature, poss geological	High		394599.7747	5932403.135

Figure 5.5.20: Wreck BA 1019

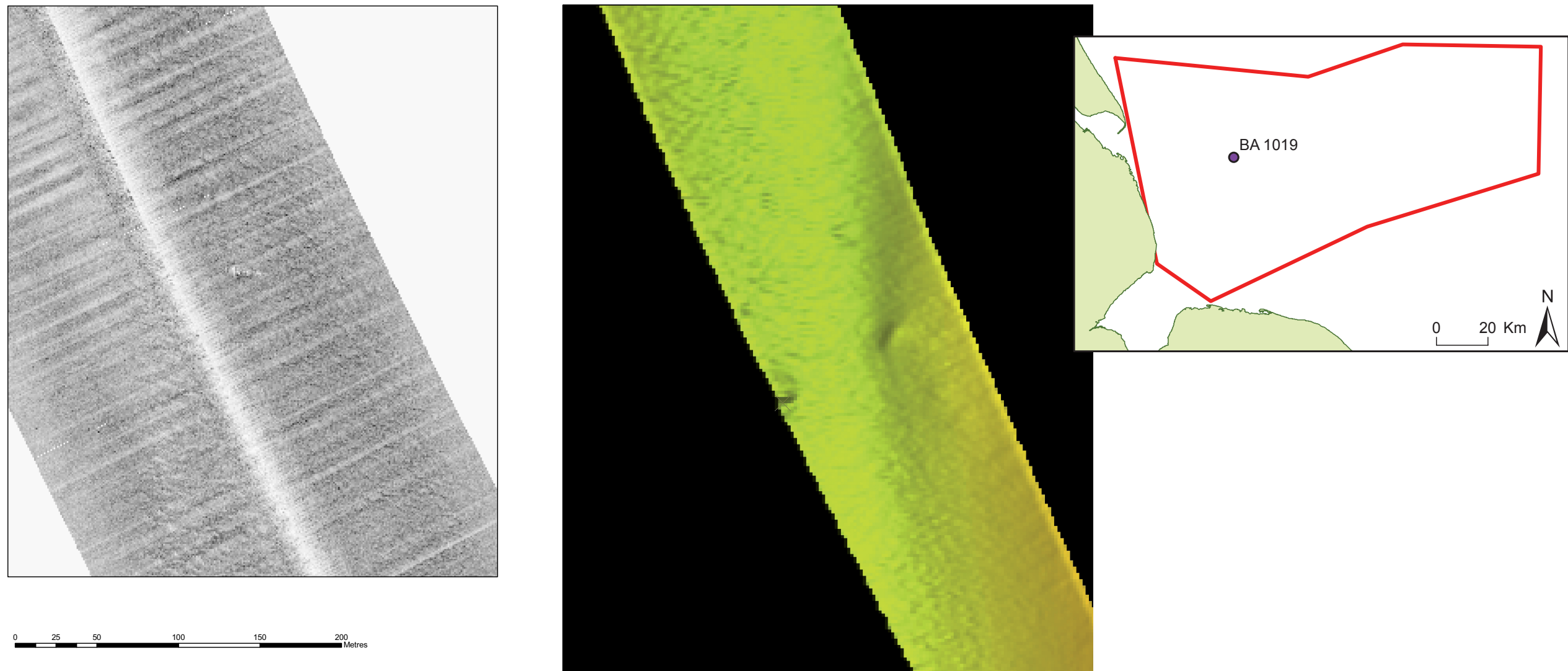


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.20	BA 1019	SM	N/A	Not on UKHO	S122	Very small anomaly	Medium	M76	Faint anomaly at edge of scan	High		353629.1	5930355.773

Figure 5.5.21: Wreck BA 1023

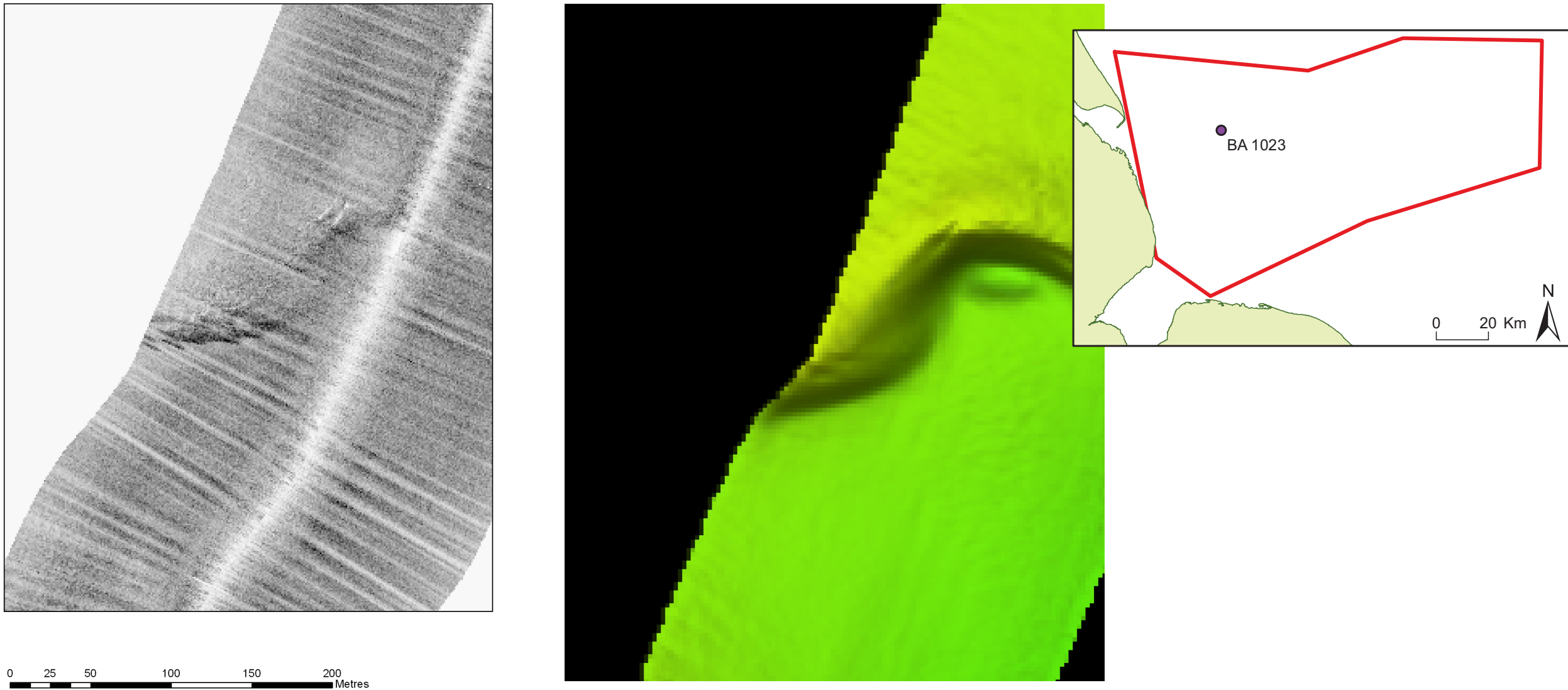


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.21	BA 1023	SM	N/A	Not on UKHO	S23	Feature, NW SE, possibly broken, covers 175 m x 30 m	High	M130	Large feature	High		348986.187	5938508.524

Figure 5.5.22: Wreck BA 1058

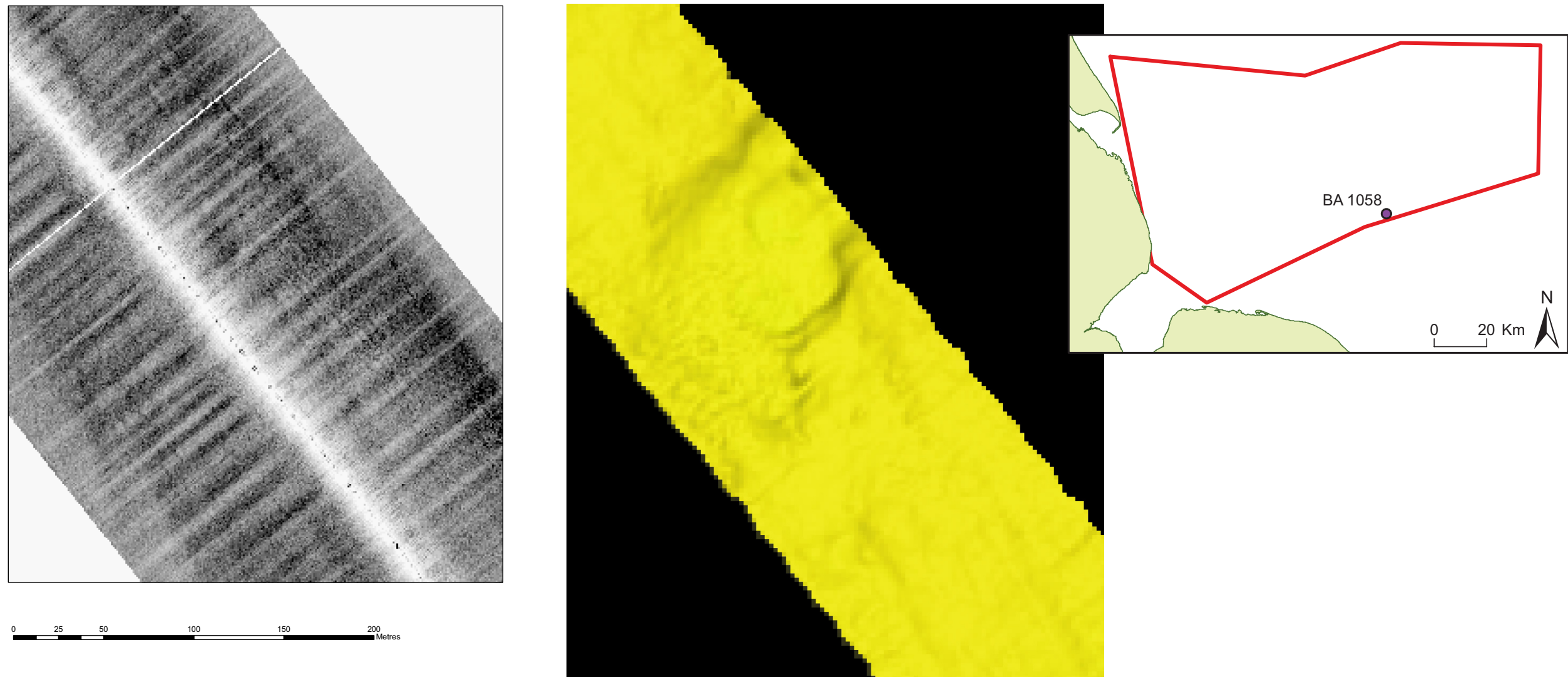


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.22	BA 1058	M	N/A	Not on UKHO	S123	Not Seen in Sidescan	N/A	MA1	High arch, large upstanding block on sandwave field (north edge) on E-W break of slope (NE-SW), current to SE	High		413628	5908737

Figure 5.5.23: Wreck BA 1059

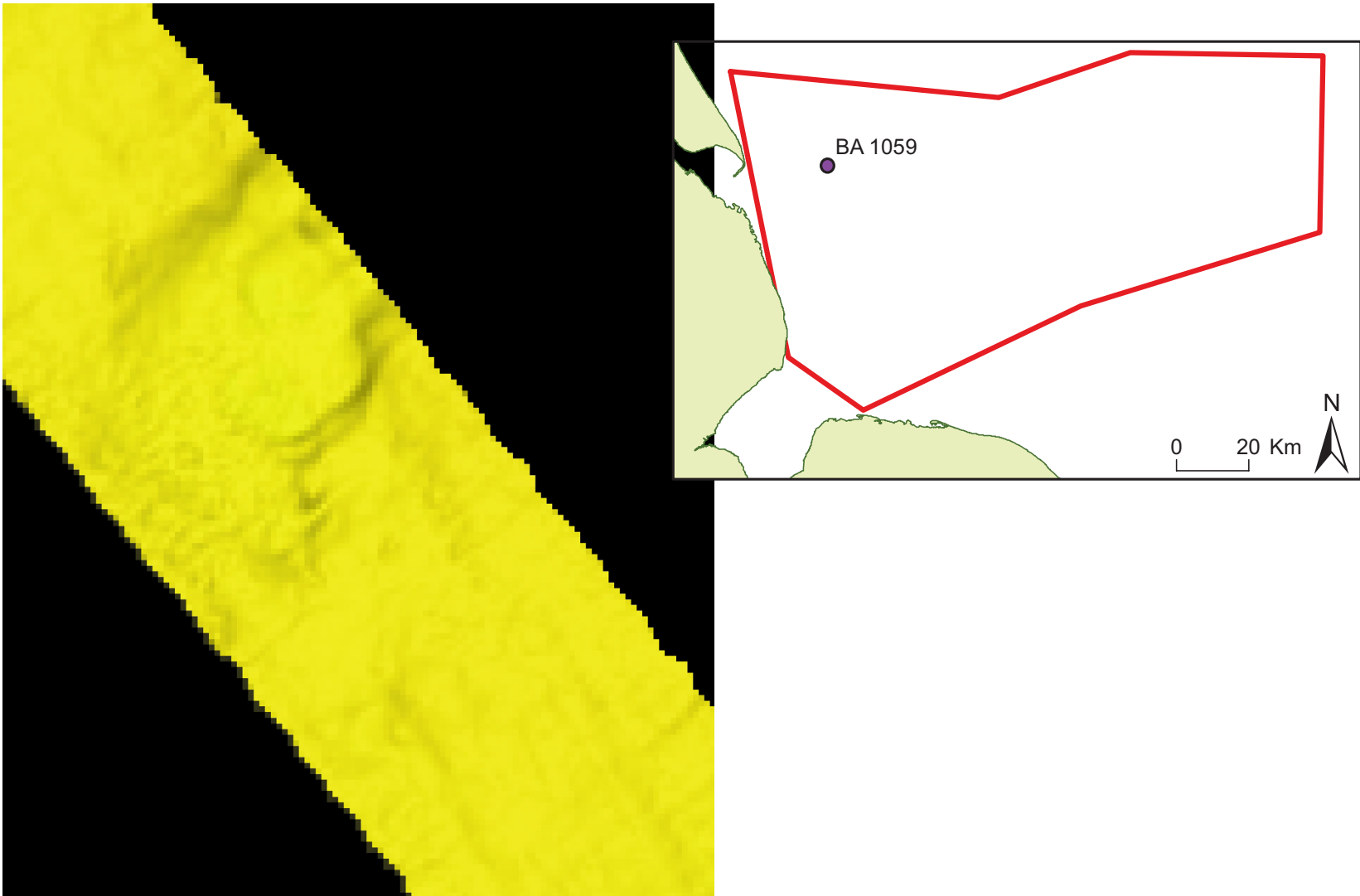
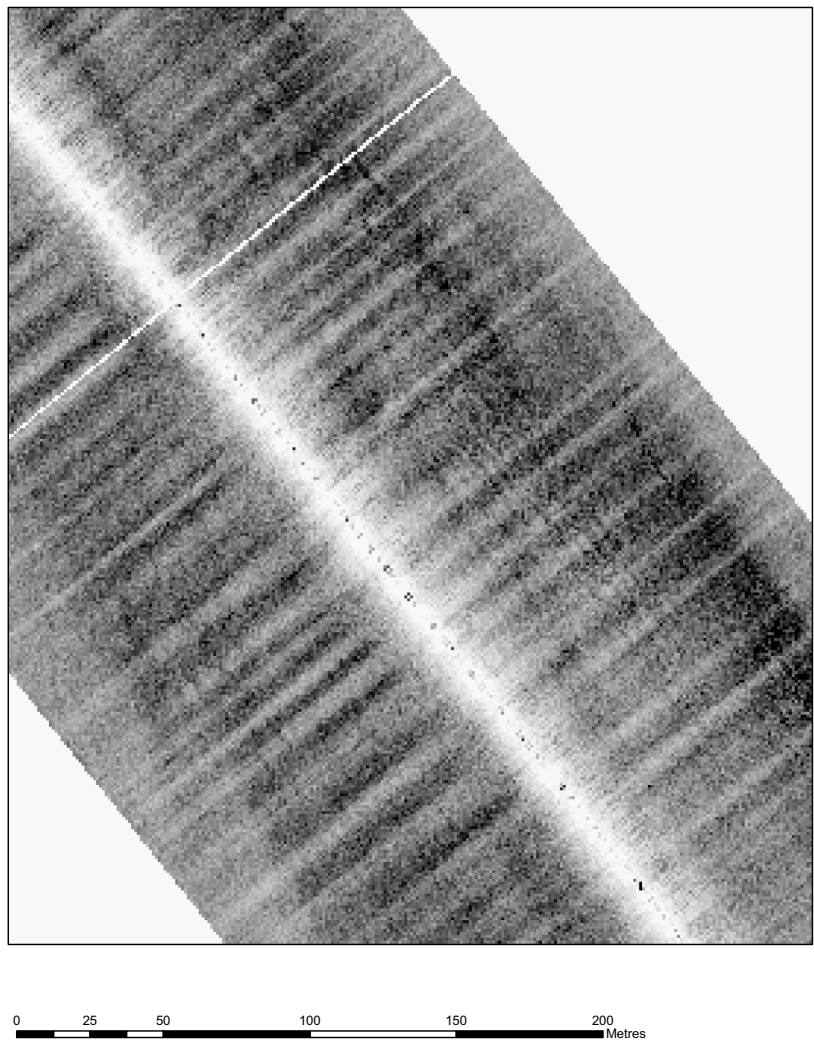


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.23	BA 1059	M	N/A	Not on UKHO	S124	Not Seen in Sidescan	N/A	MA14	High arch within sandwave	High		334881	5942778

Figure 5.5.24: Wreck BA 1060

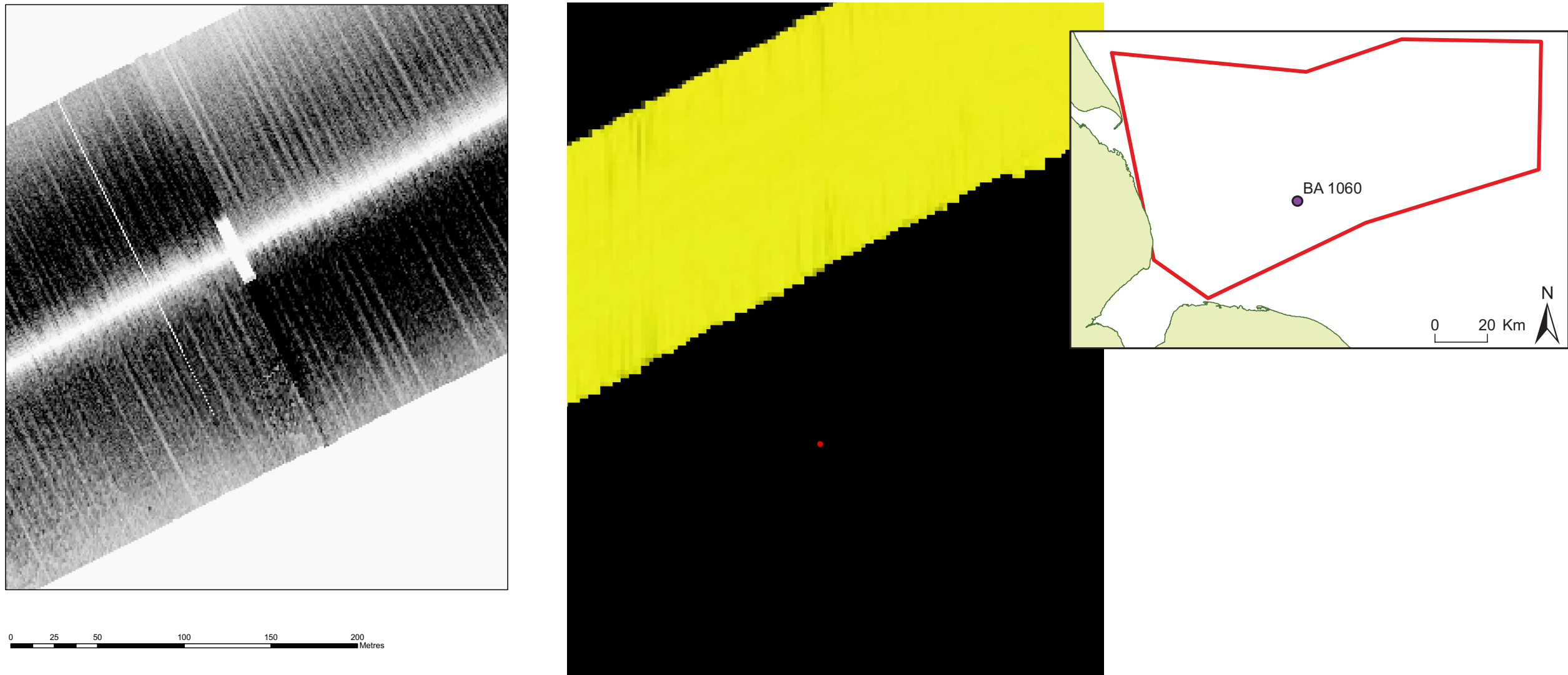


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.24	BA 1060	S	N/A	Not on UKHO	S125	Large circular feature (50 m diameter) plus rough area, geology or high arch	High/geology	MA15/16	Not on Multibeam	N/A		379072	5911956

Figure 5.5.25: Wreck BA 1061

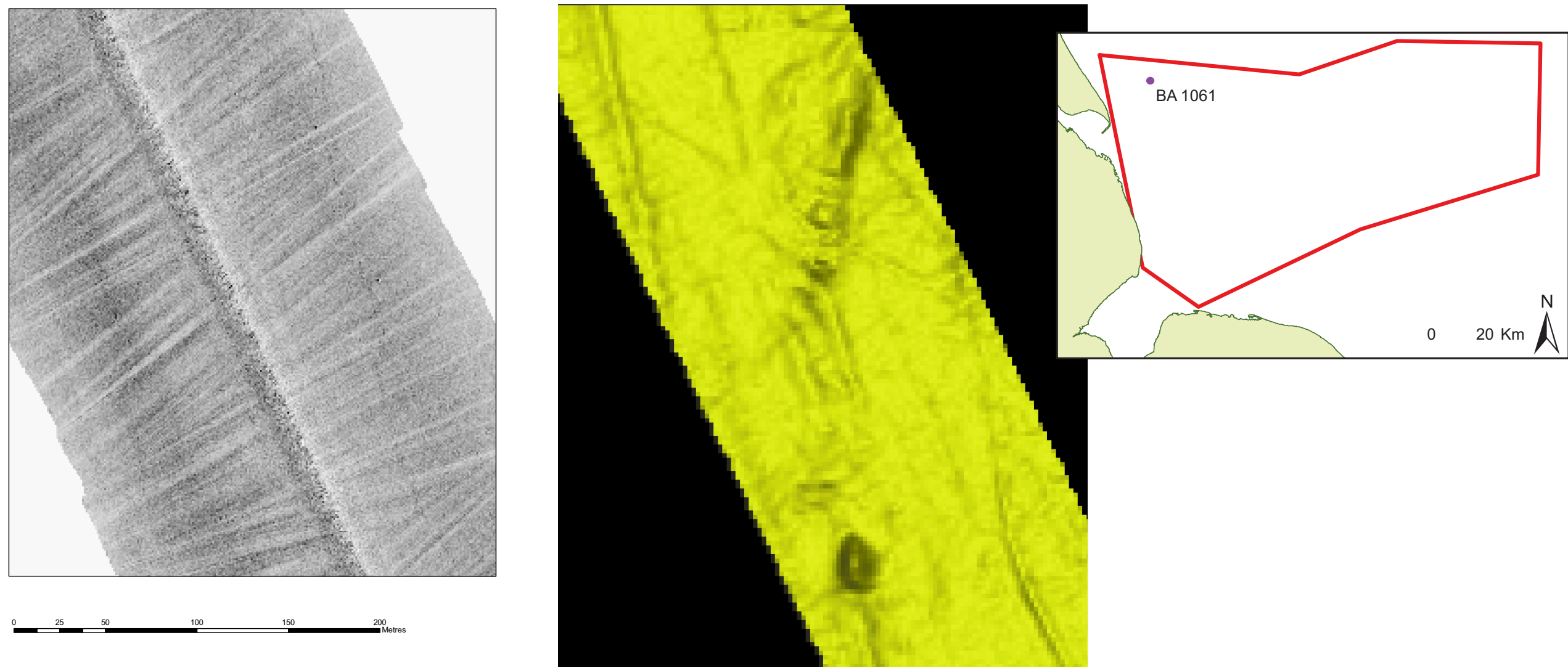


Figure No	BA no	Sidescan Sonar/ Multibeam	UKHO number	UKHO information	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	Additional Image No	UTM31N_E	UTM31N_N
5.5.25	BA 1061	M	N/A	Not on UKHO	S126	Not Seen in Sidescan	N/A	MA20	High arch, linear to north, circular to south	High		326759	5959173

BAno	Sidescan Sonar/ Multibeam	UKHO number	Sidescan Sonar image No.	Sidescan Sonar comments	Sidescan Sonar Archaeological Interpretation	Multibeam Bathymetry image No.	Multibeam Bathymetry comments	Multibeam Bathymetry Archaeological Interpretation	UTM31N_E	UTM31N_N
BA 1020	SM	sz540-2088683023-9583	S35	Very small faint anomaly	Low	M21	Small circular anomaly, more to SE but not recorded	High	357580.5104	5956045.357
BA 1021	SM		S15	Very large feature, NW SE, 81 m x 16 m, & 275 m EW similar S14	Cables on seabed, fishing gear?, some geology	M1	upright feature aligned EW	High	407973.9944	5915847.43
BA 1022	SM		S110	Linear feature, possible pipeline?	High	M114	Linear feature, pipeline?	Low	391993.336	5918631.388
BA 1023	S	SZ540-332156270	S23	Feature, NW SE, possibly broken, covers 175 m x 30 m	High	N/A	Not Seen In Multibeam	N/A	348986.187	5938508.524
BA 1024	M		N/A	Not Seen in Sidescan	N/A	M23	Cluster of small circular anomalies	High (old arch? 0 m circle)	375553.9354	5926620.897
BA 1025	SM		S12	Possible feature	Medium	M2	Faint anomaly	None	405728.1745	5918499.872
BA 1026	SM		S69	Veryfaint anomaly	Medium	M41	Small round anomaly	Medium	420632.2883	5959628.48
BA 1027	SM		S48	Small anomaly	Medium	M74	Small circular anomaly	Low	356441.1695	5924678.296
BA 1028	SM		S50	Small anomaly	Medium - low	M30	Faint anomaly	Geological	356451.2047	5924810.256
BA 1029	SM		S83	Feature, NE SW, 131 m x 33 m max	Low + fish noise	M42	Possible feature	Medium	433776.0418	5916671.315
BA 1030	SM		S84	Series of very thin wiggly lines, NW SE, up to 100 m	Fishing gear?	M43	Possible feature	Medium	434272.889	5915381.543
BA 1031	SM		S85	Similar features to S84	Fishing gear?	M47	Possible linear feature, extension of M46?	Medium	434512.2598	5914939.902
BA 1032	S		S1	Possible feature, NE SW, 28 m x 15 m	Medium	N/A	Not Seen In Multibeam	N/A	398047.9816	5927942.943
BA 1033	S		S106	Possibe small feature, roughly E W, 25 m x 6 m	Medium	N/A	Not Seen In Multibeam	N/A	377295.2131	5911139.287
BA 1034	S		S107	Possible feature, E W, 38 m x 8 m	Medium	N/A	Not Seen In Multibeam	N/A	382171.1834	5913501.005
BA 1035	S		S11	Possible feature, E W, 62 m x 5 m	Medium	N/A	Not Seen In Multibeam	N/A	412703.0648	5909937.044
BA 1036	S		S2	Small circular anomaly	Medium	N/A	Not Seen In Multibeam	N/A	389550.5944	5938627.905
BA 1037	S		S26	Feature, NW SE, 113 m x 30 m, quite faint anomaly	Medium	N/A	Not Seen In Multibeam	N/A	348919.9519	5938118.855
BA 1038	S		S4	Possible feature	Medium	N/A	Not Seen In Multibeam	N/A	394943.4167	5931821.859
BA 1039	S		S42	Small circular anomaly	Medium	N/A	Not Seen In Multibeam	N/A	340519.4047	5956510.78
BA 1040	S		S43	Possible feature or pipeline E W, 140 m x 10 m	Medium	N/A	Not Seen In Multibeam	N/A	340708.9626	5956233.116
BA 1041	S		S44	Feature, E W, 83 m x 19 m	Medium	N/A	Not Seen In Multibeam	N/A	343090.9748	5951691.596
BA 1042	S		S49	Small possible feature, N S, 12 m x 2 m	Medium	N/A	Not Seen In Multibeam	N/A	353213.4669	5931440.937
BA 1043	S		S54	Possible feature, N S, approx 74 m	Medium	N/A	Not Seen In Multibeam	N/A	335512.6645	5966606.747
BA 1044	S		S6	Feature, NW SE, 30 m x 7 m	Medium	N/A	Not Seen In Multibeam	N/A	381668.8982	5948426.126
BA 1045	S		S63	Faint anomaly, more to the south, NW SE, 70 m x 23 m	Medium	N/A	Not Seen In Multibeam	N/A	333887.8319	5945030.925
BA 1046	S		S7	Possible feature, 19 m x 11 m	Medium	N/A	Not Seen In Multibeam	N/A	382189.5173	5947798.204
BA 1047	S		S8	Possible feature, N S, 47 m x 8 m	Medium	N/A	Not Seen In Multibeam	N/A	382694.5568	5947168.982
BA 1048	S		S97	Faint anomaly, roughly N S, 30 m x 5 m	Medium	N/A	Not Seen In Multibeam	N/A	354622.5582	5952842.152
BA 1049	S		S98	Vague dispersed anomaly, roughly N S, 61 m x 23 m	Medium	N/A	Not Seen In Multibeam	N/A	354802.208	5949919.78
BA 1050	M		N/A	Not Seen in Sidescan	N/A	M122	Possible feature/ anomaly	Medium	419239.7081	5887725.627
BA 1051	M		N/A	Not Seen in Sidescan	N/A	M44	possible feature	Medium	434618.9275	5915009.494
BA 1052	M		N/A	Not Seen in Sidescan	N/A	M45	Possible feature same as M44?	Medium	434823.6639	5914666.863
BA 1053	M		N/A	Not Seen in Sidescan	N/A	M48	Linear feature, similar to M46 and M47	Medium	435657.8721	5913084.601
BA 1054	M		N/A	Not Seen in Sidescan	N/A	M62	possible feature	Medium	373410.9867	5958819.014
BA 1055	M		N/A	Not Seen in Sidescan	N/A	M32	Circular anomaly	Large pock, archaeology?	435696.0407	5960127.716
BA 1056	S		S71	Possible feature, E W, 40 m x 6 m	Medium (plus acquisition footprint)	N/A	Not Seen In Multibeam	N/A	354063.6218	5949897.444
BA 1057	S		S55	Possible feature, dispersed, or geological, E W, 55 m x 21 m	Medium/ geological	N/A	Not Seen In Multibeam	N/A	341587.2643	5954445.581
BA 1058	M		N/A	Not Seen in Sidescan	N/A	MA1	High arch, large upstanding block on sandwave field (north edge) on E–W break of slope (NE–SW), current to SE	High	413628	5908737
BA 1059	M		N/A	Not Seen in Sidescan	N/A	MA14	High arch within sandwave	High	334881	5942778
BA 1060	M		N/A	Not Seen in Sidescan	N/A	MA15/16	Large circular feature (50 m diameter) plus rough area, geology or high arch	High/ geology	379072	5911956
BA 1061	M		N/A	Not Seen in Sidescan	N/A	MA20	High arch, linear to north, circular to south	High	326759	5959173

Table 5.5.2: Additional Wreck Information.

5.6 Palaeoenvironmental Results

5.6.1 Introduction

This document describes the results of the palaeoenvironmental assessment and analysis of deposits recovered during the survey phase of the Humber REC project. The study area includes part of the submerged landscape often referred to as ‘Doggerland’ by archaeologists (e.g. Gaffney *et al.* 2007) which formed a ‘landbridge’ between the British Isles and north-west Europe prior to its submergence by rising sealevels at the end of the last (Devensian) glaciation and the start of the Holocene. The previous status of this area as dryland has implications for the preservation of material of archaeological and palaeoenvironmental significance (henceforth referred to as the archaeo-environmental record). A programme of work was devised to identify, subsample and assess deposits which were regarded as preserved *in situ* and hence with the potential to preserve significant archaeo-environmental remains. An initial report described the results of these assessments (Gearey *et al.* 2010) and resulted in a second phase of more detailed analysis of selected cores. This report incorporates the assessment and subsequent analyses of the deposits from these submarine contexts and considers the implications for the timing, processes and patterns of environmental change associated with the early Holocene inundation of ‘Doggerland’.

5.6.2 Methodology

Vibrocore recovery

A total of eight sampling locations (Figure 5.6.1) had been selected based on the analysis of geophysical data which had been interpreted as indicating the presence of features identified as possible palaeochannels. The cores were recovered using a 5m Vibrocorer operated by geotechnical engineers on board the Gardline vessel Sea Profiler. The vibrocoreing protocol involved operation for 15 minutes when the rig was in place on the sea bed. Once recovery to the deck was complete, depth of penetration was recorded and the sediment filled liner was sawed into sections for storage, capped at both ends then wrapped in polythene for storage. If sediment recovery was regarded as insufficient, then up to two more attempts were permitted. At some locations, if the stratigraphic sequence was shallow and clearly of low

palaeoenvironmental potential (i.e. sea bottom sediments directly onto boulder clay), then only a single core was recovered. At locations of greater potential, generally apparent through recovery of more significant depths of sediment (e.g. 2 m+), duplicate cores were usually recovered.

Stratigraphic recording

The cores were removed from the Sea Profiler upon return to port for transport directly to the University of Birmingham. The plastic liners were subsequently opened using the dedicated core splitter at Gardline’s laboratory in Great Yarmouth. Sediment stratigraphy was then recorded for all cores (Plate 5.6.1) using the Troels-Smith (1955) system with soil colours determined using the standard Munsell Chart. Photography of selected cores was also



Plate 5.6.1: Recording and sub-sampling the cores.

undertaken. All stratigraphic information was entered directly into a database. Core logs with full Troels-Smith (1955) descriptions are presented in Appendix B.

This section summarises the results of the palaeoenvironmental assessments of the eleven cores regarded as of high palaeoenvironmental potential. Potential was judged on the basis of the total depth of the recovered deposits and the results of the stratigraphic recording. Sequences which included peat deposits and other organic sediments were initially targeted. The sequences discussed in this report represent eight groups which were selected for sampling on the basis of the geophysical data.

Pollen assessments and analyses

The cores were initially sub-sampled by taking 1 cm³ of sediment, with a total of 31 samples assessed for pollen from vibrocores (hence forth VC) 16, 18, 29, 29a, 48, 49, 50 and 51). The initial assessment of these samples (see also Appendix C) led to the selection of 6 cores for more detailed pollen analysis (See Table 5.6.1: VC 29, 29b, 48, 50, 51 and 51a) at sampling intervals of either 0.08 m or 0.04 m (see below). Pollen preparation followed standard techniques including potassium hydroxide (KOH) digestion, hydrofluoric acid (HF) treatment and acetylation (Moore *et al.* 1991). For assessment, at least 125 total land pollen grains (TLP) excluding aquatics and spores were counted for each sample using a Nikon Eclipse 50i microscope. Full analyses attempted a count of 300 TLP, although this sum was not always attained for samples with low pollen concentrations or poor preservation. Pollen nomenclature follows Moore *et al.* (1991) with the modifications suggested by Bennett *et al.* (1994).

Core	Dates		Pollen	Plant Macros	Beetles	Ostracods/ forams	Diatoms
	RC	OSL					
VC 29							
VC 29b							
VC 48							
VC50							
VC51							
VC51a							

Table 5.6.1: Summary of the detailed analyses of the six selected cores.



Figure 5.6.1: Vibrocore sampling locations within Humber REC zone.

Assessment of pollen concentration and preservation was carried out using a semi-quantitative five point scale whereby a value of 1 indicates very low concentration or very poor preservation and 5 indicates very high concentration and excellent preservation.

Ostracoda and foraminifera assessments

Duplicate subsamples were also taken for assessment of calcareous microfossil (ostracods and foraminifera). A total of 41 samples from VC 17, 18, 29, 39, 48, 50 and 51 were processed using standard preparation techniques for unconsolidated clays and silts. A relatively high proportion of the sub-samples (17) did not contain any recognisable foraminifera or ostracods, which is presumably a primary signal (i.e. such microfossils were never present), since many of these samples contain fragments of larger calcitic invertebrates. It is not possible to speculate more precisely regarding this absence. On the basis of the assessments, more detailed analyses were carried out on VC 29, 29b and 50.

The results of the initial assessments are presented in Table 5.6.2 with the analyses of VC 29, 29b and 50 presented separately (see below). Species were recorded as being rare (<4 specimens), common (4–10 specimens) or abundant (>10 specimens) and were grouped into environmental categories as outlined in Table 5.6.3. Note that the species are not exclusive to these categories but are generally most abundant in habitats that reflect those conditions.

Beetle and plant macrofossil analyses and assessments

Bulk samples from 6 selected cores (VC 29, 29b, 48, 50, 51 and 51a) were processed using the standard method of paraffin flotation as outlined in Kenward *et al.* (1980). Insect remains were sorted and identified under a low-power binocular microscope at magnifications between x15–x45. Where possible, the insect remains were identified to species level by direct comparison with specimens in the Gorham and Girling insect collections housed in the Institute of Archaeology and Antiquity, University of Birmingham. The insect remains recorded are all beetles (Coleoptera). Given the relatively small volume of material processed the insect faunas are comparatively large and are well preserved (based on the criteria listed in Kenward and Hall 2006). A full list of Coleoptera recovered is presented in Appendix D. The nomenclature for Coleoptera (beetles) follows that of Lucht (1987).

The beetle flot remainders together with the paraffin residue were washed through a sieve with 300 µm mesh using a mixture

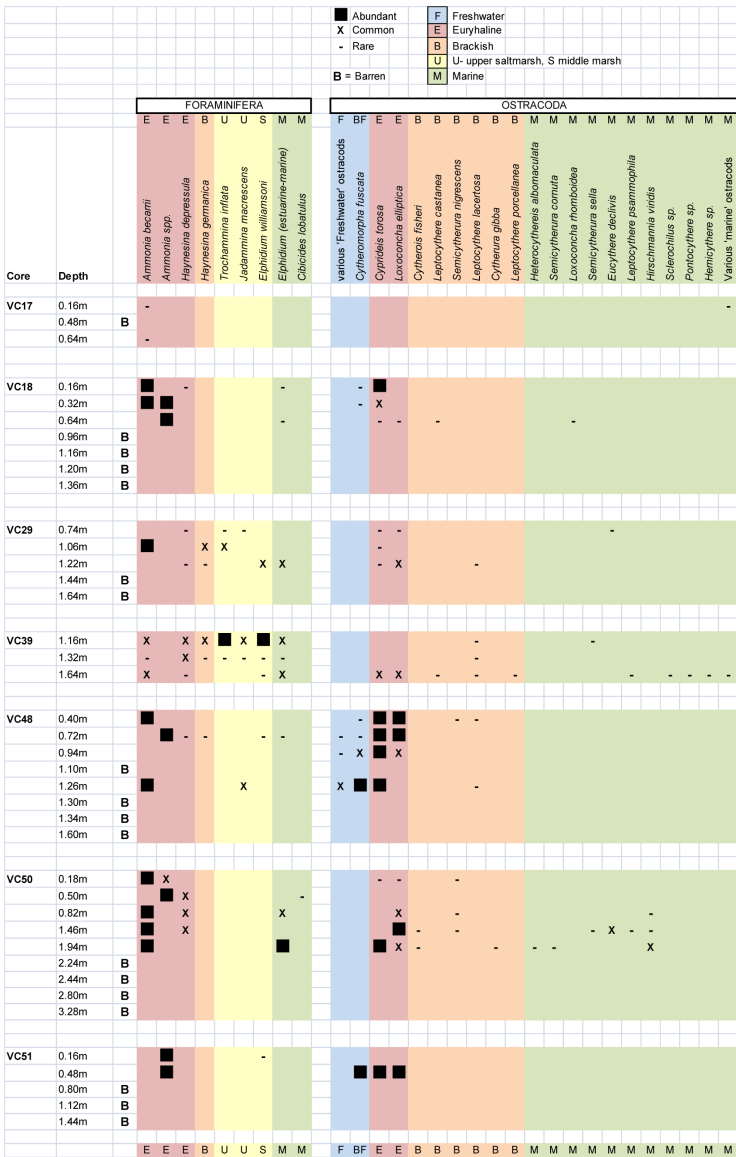


Table 5.6.2: Results of the foram/ostracod assessments.

of detergent and water in order to remove the paraffin from the remaining organic material. The processed samples were sorted and material identified, under a low power binocular microscope at magnifications of x10 and x40 to retrieve waterlogged plant remains. Identification was aided by use of a modern comparative collection and by using various seed identification manuals, although all identifications are provisional at this stage (Anderberg, 1994; Beijerinck 1947 and Berggren 1969 & 1981 and Cappers *et al.* 2006). The plant nomenclature and habitat information follows Stace (1997).

Radiocarbon Dating and chronological modelling

Six samples were initially taken for radiocarbon dating from VC 16, 29, 48 and 50. These sequences were targeted as they contained plant macrofossils including *Corylus* fruits (hazelnuts) and sub-fossil wood remains which could confidently be regarded as having been deposited *in situ*. The samples were submitted to Beta Analytic Inc, Miami, Florida for dating using the AMS method (see Table 5.6.4).

Habitat	Foraminifera
Euryhaline	<i>Ammonia beccarii</i>
Euryhaline	<i>Ammonia spp.</i>
Euryhaline	<i>Haynesina depressula</i>
Brackish	<i>Haynesina germanica</i>
Upper saltmarsh	<i>Trochammina inflata</i>
Upper saltmarsh	<i>Jadammina macrescens</i>
Middle marsh	<i>Elphidium williamsoni</i>
Marine	<i>Elphidium (estuarine-marine taxa)</i>
Marine	<i>Cibicides lobatulus</i>
Ostracoda	
Freshwater	Various 'Freshwater' ostracods
Brackish-Freshwater	<i>Cytheromorpha fuscata</i>
Euryhaline	<i>Cyprideis torosa</i>
Euryhaline	<i>Loxoconcha elliptica</i>
Brackish	<i>Cytherois fisheri</i>
Brackish	<i>Leptocythere castanea</i>
Brackish	<i>Semicytherura nigrescens</i>
Brackish	<i>Leptocythere lacertosa</i>
Brackish	<i>Cytherura gibba</i>
Brackish	<i>Leptocythere porcellanea</i>
Marine	<i>Heterocythereis albomaculata</i>
Marine	<i>Semicytherura cornuta</i>
Marine	<i>Loxoconcha rhomboidea</i>
Marine	<i>Semicytherura sella</i>
Marine	<i>Eucythere declivis</i>
Marine	<i>Leptocythere psammophila</i>
Marine	<i>Hirschmannia viridis</i>
Marine	<i>Sclerochilus sp.</i>
Marine	<i>Pontocythere sp.</i>
Marine	<i>Hemicythere sp.</i>

Table 5.6.3: Ostracod and Foraminifera environmental categories.

The OSL (with the exception of that from VC 47a, see below) and radiocarbon chronologies from VC 29, 39, 50 and 51 have been modelled using a Bayesian approach. Details of Bayesian age modelling have been widely covered in the literature (e.g. Blaauw and Christen 2005; Blaauw *et al.* 2007a, 2007b; Bronk Ramsey 2008). All the models were produced using a U-Sequence or uniform deposition model (Bronk Ramsey 2008), in which the accumulation rate is unknown but is assumed to be constant (Christen *et al.* 1995), an approach often favoured in palaeoecological research (e.g. Barber *et al.* 2003; Chiverrell 2001). The date ranges produced in the tables below for each modelled sequence (VC 29b, 39a, 50 and 51a) in italics are posterior density estimates derived from this Bayesian mathematical modelling of the OSL and radiocarbon chronologies (Bayliss *et al.* 2007). They are interpretative estimates, which can and will change as further data become available and as other researchers choose to add to or model the data from different perspectives.

Sample/Depth	Material	$\delta^{13}\text{C}$ (‰)	Radiocarbon Age (BP)	Calibrated Date (95% confidence)
Lab code				
VC16–1.61 m Beta-277314	Wood	-28.8	8420 ± 50 BP	7580–7450 cal BC
VC29–1.40 m Beta-260805	Wood	-26.9‰	8090 ± 50 BP	7180–6840 cal BC
VC48–1.30 m Beta-260806	Wood	-27.4‰	8060 ± 50 BP	7140–6820 cal BC
VC50–2.18 m Beta-280040	Fruitwood	-27.5‰	8130 ± 40 BP	Cal BC 7180 to 7050
VC50–2.34 m Beta-260807	Wood	-27.5‰	7930 ± 50 BP	7050–6640 cal BC
VC50–2.44 m Beta-260808	<i>Corylus</i> Nut	-25.0‰	8180 ± 50 BP	7350–7050 cal BC
VC 50–2.48 m Beta-260809	<i>Corylus</i> Nut	-25.1‰	8230 ± 50 BP	7460–7070 cal BC

Table 5.6.4: Results of the radiocarbon dating.

Optically Stimulated Luminescence dating (OSL)

Optically Stimulated Luminescence dating (OSL) to ‘The value of optical dating in this context is centred upon the lack of *in situ* organic remains in minerogenic silts and clays which account for the greater proportion of the recovered material. This inorganic dating technique is able to directly date sedimentary events drawing

Generic considerations	Field Code	Lab Code	Sample specific considerations
Absence of γ spectrometry data (see 4.0)	V29B 0.59–0.69	GL09061	Accept
	V29B 0.89–0.99	GL09062	Accept
	V29B 1.20–1.28	GL09063	Accept
	V29B 1.52–1.58	GL09064	Accept
	V29B 1.84–1.90	GL09065	Accept
	V29B 1.98–2.04	GL09066	Accept
	VC39A 0.45–0.55	GL09067	Accept
	VC39A 1.02–1.10	GL09068	Accept
	VC39A 1.44–1.54	GL09069	Accept
	VC39A 2.16–2.26	GL09070	Accept
	VC47A 0.30–0.40	GL09071	Overdispersion of regenerative-dose data (see 3.1.4; Fig. 5)
			Accept tentatively
	VC47A 0.58–0.66	GL09072	Accept
	VC47A 0.99–1.10	GL09073	Overdispersion of regenerative-dose data (see 3.1.4; Fig. 5)
			Accept tentatively
	VC47A 2.25-2.35	GL09074	Feldspar contamination (see 3.1.1; Fig. 6)
			Partially bleached (see 3.2.1)
			Reject
	VC47A 3.95–4.05	GL09075	Partially bleached (see 3.2.1)
			Accept as maximum age estimate
	VC51A 0.60–0.70	GL09076	Accept
	VC51A 0.90–1.00	GL09077	Accept
	VC51A 1.07–1.17	GL09078	Accept

Table 5.6.5: Analytical validity of OSL sample suite age estimates and associated caveats.

upon the time-dependent optically stimulated luminescence signal contained with natural sedimentary quartz. The mean age is a quotient of the mean natural dose absorbed since burial (D_e value) and mean dose rate during that interval (D_r value).

A total of 18 samples were taken for Optical dating from sedimentary units comprising fine sand or fine silt. Quartz was isolated principally by acid digestion and density separation. Age estimates were derived from multi-grain, single aliquots (D_e value, Murray and Wintle, 2000; 2003) and assessment of lithogenic plus

cosmogenic radiation flux (D_r value; by Ge gamma spectrometry and the calculations of Prescott and Hutton, 1994).

5.6.3 Results

This section will present the results of the assessment and subsequent analysis phase of the selected cores. This will be followed by an interpretation of these data by coring group (Figure 5.6.1) prior to a discussion of the significance of the results of this phase of the REC project in terms of understanding of the environmental history of this part of the southern North Sea. The detailed stratigraphic records of all the cores recovered during the ‘ground truthing’ stage are given in Appendix B.

General discussion: plant macrofossils

Preservation of plant remains (see Appendix D for detailed results) was almost exclusively by anoxic ‘waterlogging’ and macrofossils, particularly fruits and seeds, were generally quite well preserved, sometimes showing a degree of silt coating and deposition within the tissues of iron pyrites. In a few samples a little charred material was encountered: mainly this was wood charcoal, but at 1.32–1.60 m in Core 48 there were some charred *Cenococcum sclerotia* (resting bodies of a soil fungus) and small charred root fragments. These seem likely to have arrived in the deposit through the inwash of soil which had been subjected to burning at the surface, although whether this burning was natural or a result of human activity cannot be determined. Wood charcoal was noted in two of the cores at the following depths: VC 48–1.32–1.60 m, a trace to 5 mm in maximum dimension; VC 51a–0.47–0.95 m, a modest quantity to 25 mm.

By far the greatest part of the organic material could not be identified more closely than ‘rhizome fragments’, ‘bark fragments’ or even just ‘herbaceous detritus’, although it is possible that further study of well preserved fragments of surviving epidermis could provide some closer determinations. Plant diversity was rather low, perhaps indicating that these deposits did not form through the accumulation of material from a wide area. This is consistent with the very fine-grained nature of the mineral component of many of the samples, but possibly less so with the interpretation of the majority of the sampling sites as palaeochannels.

Field Code	Lab Code	Location	Overburden (m)	Grain size (µm)	Moisture content (%)	NaI γ -spectrometry (in situ)			γ Dr (Gy.ka ⁻¹)	Ge γ -spectrometry (lab based)			α Dr (Gy.ka ⁻¹)	β Dr (Gy.ka ⁻¹)	Cosmic Dr (Gy.ka ⁻¹)	Total Dr (Gy.ka ⁻¹)	Preheat (°C for 10s)	D _e (Gy)	Age (ka)
						K (%)	Th (ppm)	U (ppm)		K (%)	Th (ppm)	U (ppm)							
V29B 0.59–0.69	GL09061	54°N, 0°E, 0 m	0.64	125–180	15 ± 4	-	-	-	0.44 ± 0.05	0.84 ± 0.04	4.24 ± 0.38	1.03 ± 0.07	-	0.70 ± 0.07	0.19 ± 0.02	1.33 ± 0.09	240	8.6 ± 0.3	6.5 ± 0.5 (0.4)
V29B 0.89–0.99	GL09062	54°N, 0°E, 0 m	0.99	May–15	15 ± 4	-	-	-	1.02 ± 0.07	2.10 ± 0.09	9.77 ± 0.59	2.19 ± 0.12	0.43 ± 0.04	1.84 ± 0.15	0.18 ± 0.02	3.46 ± 0.17	260	20.4 ± 0.8	5.9 ± 0.4 (0.3)
V29B 1.20–1.28	GL09063	54°N, 0°E, 0 m	1.24	May–15	40 ± 10	-	-	-	0.68 ± 0.11	1.99 ± 0.10	10.64 ± 0.75	1.85 ± 0.13	0.26 ± 0.05	1.14 ± 0.20	0.17 ± 0.02	2.25 ± 0.23	260	18.0 ± 1.0	8.0 ± 0.9 (0.9)
V29B 1.52–1.58	GL09064	54°N, 0°E, 0 m	1.55	May–15	33 ± 8	-	-	-	0.59 ± 0.08	1.35 ± 0.06	7.76 ± 0.53	2.00 ± 0.11	0.26 ± 0.04	0.96 ± 0.14	0.16 ± 0.02	1.97 ± 0.17	260	25.4 ± 0.9	12.9 ± 1.2 (1.1)
V29B 1.84–1.90	GL09065	54°N, 0°E, 0 m	1.87	May–15	23 ± 6	-	-	-	0.67 ± 0.07	1.14 ± 0.06	8.42 ± 0.56	1.88 ± 0.11	0.32 ± 0.04	1.02 ± 0.11	0.15 ± 0.01	2.16 ± 0.13	240	50.6 ± 2.3	23 ± 2 (2)
V29B 1.98–2.04	GL09066	54°N, 0°E, 0 m	2.01	125–180	11 ± 3	-	-	-	0.56 ± 0.06	1.07 ± 0.05	5.12 ± 0.41	1.21 ± 0.08	-	0.91 ± 0.09	0.15 ± 0.01	1.62 ± 0.10	260	43.8 ± 2.8	27 ± 2 (2)
VC39A 0.45–0.55	GL09067	54°N, 0°E, 0 m	0.5	125–180	13 ± 3	-	-	-	0.35 ± 0.05	0.75 ± 0.04	3.00 ± 0.32	0.76 ± 0.06	-	0.61 ± 0.06	0.19 ± 0.03	1.15 ± 0.08	240	12.1 ± 1.4	10.5 ± 1.4 (1.3)
VC39A 1.02–1.10	GL09068	54°N, 0°E, 0 m	1.06	125–180	15 ± 4	-	-	-	0.44 ± 0.05	0.87 ± 0.05	4.27 ± 0.36	1.03 ± 0.07	-	0.71 ± 0.07	0.17 ± 0.02	1.32 ± 0.10	240	12.7 ± 0.6	9.6 ± 0.8 (0.7)
VC39A 1.44–1.54	GL09069	54°N, 0°E, 0 m	1.49	May–15	15 ± 4	-	-	-	0.81 ± 0.06	1.74 ± 0.08	7.67 ± 0.50	1.70 ± 0.10	0.33 ± 0.03	1.49 ± 0.12	0.16 ± 0.02	2.79 ± 0.14	240	26.0 ± 1.1	9.3 ± 0.6 (0.5)
VC39A 2.16–2.26	GL09070	54°N, 0°E, 0 m	2.21	May–15	21 ± 5	-	-	-	0.81 ± 0.08	1.92 ± 0.09	8.07 ± 0.50	1.82 ± 0.10	0.32 ± 0.04	1.48 ± 0.15	0.14 ± 0.01	2.75 ± 0.18	220	23.6 ± 1.1	8.6 ± 0.7 (0.5)
VC47A 0.30–0.40	GL09071	54°N, 0°E, 0 m	0.35	125–180	22 ± 6	-	-	-	0.27 ± 0.04	0.72 ± 0.04	2.57 ± 0.32	0.57 ± 0.06	-	0.49 ± 0.06	0.20 ± 0.03	0.96 ± 0.09	220	0.10 ± 0.01	0.11 ± 0.02 (0.02)
VC47A 0.58–0.66	GL09072	54°N, 0°E, 0 m	0.62	125–180	17 ± 4	-	-	-	0.32 ± 0.04	0.68 ± 0.04	3.13 ± 0.34	0.73 ± 0.06	-	0.53 ± 0.06	0.19 ± 0.02	1.04 ± 0.08	220	0.33 ± 0.03	0.32 ± 0.04 (0.03)
VC47A 0.99–1.10	GL09073	54°N, 0°E, 0 m	1.04	125–180	17 ± 4	-	-	-	0.35 ± 0.05	0.74 ± 0.04	3.19 ± 0.33	0.82 ± 0.06	-	0.58 ± 0.06	0.18 ± 0.02	1.10 ± 0.08	220	0.94 ± 0.06	0.86 ± 0.09 (0.08)
VC47A 2.25–2.35	GL09074	54°N, 0°E, 0 m	2.3	125–180	16 ± 4	-	-	-	0.45 ± 0.06	0.97 ± 0.05	4.22 ± 0.38	0.96 ± 0.07	-	0.75 ± 0.08	0.14 ± 0.01	1.34 ± 0.10	260	43.6 ± 9.3	33 ± 7 (7)
VC47A 3.95–4.05	GL09075	54°N, 0°E, 0 m	4	125–180	18 ± 4	-	-	-	0.42 ± 0.05	0.92 ± 0.05	4.01 ± 0.35	0.93 ± 0.07	-	0.70 ± 0.08	0.11 ± 0.01	1.23 ± 0.10	240	22.9 ± 3.3	19 ± 3 (3)
VC51A 0.60–0.70	GL09076	54°N, 0°E, 0 m	0.65	May–15	38 ± 10	-	-	-	0.71 ± 0.11	1.98 ± 0.09	9.74 ± 0.59	2.38 ± 0.13	0.29 ± 0.05	1.22 ± 0.20	0.19 ± 0.02	2.41 ± 0.23	240	18.8 ± 1.1	7.8 ± 0.9 (0.8)
VC51A 0.90–1.00	GL09077	54°N, 0°E, 0 m	0.95	May–15	43 ± 11	-	-	-	0.57 ± 0.10	1.78 ± 0.08	9.16 ± 0.56	1.68 ± 0.10	0.22 ± 0.04	0.98 ± 0.17	0.18 ± 0.02	1.95 ± 0.20	240	116.6 ± 8.6	60 ± 8 (7)
VC51A 1.07–1.17	GL09078	54°N, 0°E, 0m	2.01.12	May-15	17 ± 4	-	-	-	0.74 ± 0.06	1.50 ± 0.07	7.85 ± 0.52	1.62 ± 0.10	0.32 ± 0.03	1.28 ± 0.12	0.17 ± 0.02	2.51 ± 0.14	280	201.6 ± 21.1	80 ± 9 (9)

Table 5.6.6: OSL dating results and associated sample data.**OSL dating results: general discussion**

Age estimates reported in Table 5.6.6 provide an estimate of sediment burial period based on mean D_e and D_r values and their associated analytical uncertainties. Uncertainty in age estimates is reported as a product of systematic and experimental errors, with the magnitude of experimental errors alone shown in parenthesis. Where uncertainty in these parameters exists this age range may prove instructive, however the combined extremes represented should not be construed as preferred age estimates. The analytical validity of each sample is presented in Table 5.6.6.

Analytical uncertainty

All errors are based upon analytical uncertainty and quoted at 1s confidence. Error calculations account for the propagation of systematic and/or experimental (random) errors associated with D_e and D_r values. For D_e values, systematic errors are confined to laboratory b source calibration. Uncertainty in this respect is that combined from the delivery of the calibrating g dose (1.2%; NPL, pers. comm.), the conversion of this dose for SiO₂ using the respective mass energy-absorption coefficient (2%; Hubbell, 1982) and experimental error, totalling 3.5%. Mass attenuation

and bremsstrahlung losses during g dose delivery are considered negligible. Experimental errors relate to D_e interpolation using sensitisation corrected dose responses. Natural and regenerated sensitisation corrected dose points (S_i) were quantified by:

$S_i = (D_i - x.L_i) / (d_i - x.L_i)$ (Eq.1), where

D_i = Natural or regenerated OSL, initial 0.2 s;

L_i = Background natural or regenerated OSL, final 5 s;

d_i = Test dose OSL, initial 0.2 s;

x = Scaling factor, 0.08.

The error on each signal parameter is based on counting statistics, reflected by the square-root of measured values. The propagation of these errors within Eq. 1 generating σ_{Si} follows the general formula given in Eq. 2. σ_{Si} was then used to define fitting and interpolation errors within exponential plus linear regressions. For Dr values, systematic errors accommodate uncertainty in radionuclide conversion factors (5%), β attenuation coefficients (5%), α -value (4%; derived from a systematic α source uncertainty of 3.5% and experimental error), matrix density (0.20 g.cm⁻³), vertical thickness of sampled section (specific to sample collection device), saturation moisture content (3%), moisture content attenuation (2%), burial moisture content (25% relative, unless direct evidence exists of the magnitude and period of differing content) and NaI gamma spectrometer calibration (3%). Experimental errors are associated with radionuclide quantification for each sample by NaI and Ge gamma spectrometry.

The propagation of these errors through to age calculation was quantified using the expression: $\sigma_y (\delta y/\delta x) = (\sum ((\delta y/\delta x_n) \cdot \sigma_{x_n})^2)^{1/2}$, where y is a value equivalent to that function comprising terms x_n and where σ_{y_i} and σ_{x_n} are associated uncertainties. Errors on age estimates are presented as combined systematic and experimental errors and experimental errors alone. The former (combined) error should be considered when comparing luminescence ages herein with independent chronometric controls. The latter assumes systematic errors are common to luminescence age estimates generated by means identical to those detailed herein and enable direct comparison with those estimates.

General discussion: pollen analyses

The sequences for further pollen analysis were selected on the basis of the assessment phase, with those cores demonstrating good preservation of pollen identified as having potential for more detailed study. This process was also dictated in part by the total depth of organic sediment recovered in each core as well as the availability of associated dating control and the preservation of associated proxy data (plant macrofossils, beetles) as also determined by the assessment phase. In the case of VC 29 and VC 51, the availability of duplicate cores presented an opportunity to carry out integrated multi-proxy analyses. Full pollen analyses of these cores was thus undertaken to correlate the records from the

duplicate cores. This also presented a chance to investigate the extent to which a single core from such offshore contexts may be regarded as representative of a single sampling location.

The pollen diagrams below were generated using the computer programmes TILIA and TILIA*GRAPH (Grimm 1991). Generally, such diagrams will be sub-divided into local pollen assemblage zones on the basis of biostratigraphic changes. However, in the case of VC 29b, 48 and 50, the pollen spectra from these cores are so homogeneous that the diagrams are presented un-zoned. This will be discussed further below.

Assessment and Analyses results by core

VC 16

Coring group:	4 (see Fig. 1 Figure 5.6.1)
Total recovery:	2.00 m
Northing:	5906786.63
Easting:	368546.94
Water depth:	22.9 m

Stratigraphy and sub-sampling summary

Pollen assessment

Three samples were taken from this core (0.16, 0.36 and 0.60 m), the two upper samples from the top and bottom of grey brown silts and the basal sample from the base of the well humified silty-sandy peat. The samples from 0.16 m and 0.32 m had excellent to good concentration and preservation, but no pollen was present in that from 0.60 m. *Corylus avellana*-type (most probably referable to hazel rather than the morphologically similar *Myrica gale*) was the dominant species at 60% with *Quercus* (oak), *Betula* (birch), *Ulmus* (elm) and *Pinus sylvestris* (Scots pine) also recorded. Other trees and shrubs including *Fraxinus* (ash), *Salix* (willow) and *Hedera helix* (ivy) were recorded at trace values. Poaceae (wild grasses) was the main herbaceous taxa but with Cyperaceae (sedges) also present in both samples.

The implied environment was predominantly mixed woodland dominated by hazel but with small open grassy areas. The other trees and shrubs were either restricted locally or formed more significant extents at some distance from the site. Areas of still or slow flowing water are suggested by the presence of aquatic

species such as *Sparganium* (bur-reed) and *Potamogeton* (pondweed) and it is likely that some of the grasses and sedges present were associated with this wetland area (e.g. *Phragmites australis* — common reed).

Depth/m	Troels Smith	Description
0–0.15	Gmin2 Gmaj2 Ptm++	Coarse shelly sands
0.15–0.50	Ag4 Dg+	Grey brown silts, rare humified organics
0.50–0.60	Sh2 Ag1 Gmin1	Brown well humified silty peat with fine sands
0.60–0.64	As3 Gmin1 Gmin++	Grey/brown slightly organic clay with sand and some coarse small gravels
0.64–1.00	As3 Gmin1	Grades into blue grey clay with coarse sands
1.00–2.00	As4 Ptm+	Grey brown dense clay with calcareous fragments and chalky pebbles

Table 5.6.7: Sedimentary description of VC16.

Chronology

A date of 8420 ± 50 BP (Beta-277314; 7580–7450 cal. BC) obtained on a sub-fossil wood fragment from the basal clay (1.61 m) indicates that this unit was deposited during the early Holocene.

VC 17

Coring group:	4 (see Fig. 1 Figure 5.6.1)
Total recovery:	2.15 m
Northing:	5906894.09
Easting:	368837.85
Water depth:	25.3 m

Stratigraphy and subsampling summary

Ostracoda and foraminifera assessment

Three samples were assessed (0.16, 0.48 and 0.64 m) but one was barren (0.48 m) and the remaining two (0.16 and 0.64 m) contained only rare occurrences of the euryhaline foram *Ammonia beccarii* and a few ostracods of marine aspect. It is not possible to draw meaningful conclusions from these data, but the absence of brackish taxa may suggest an open marine influence.

Core	Depth	Sediment	Pollen	Ostracods	Bulks	Dates
VC16	0.20 m	Grey brown silts, rare humified organics				
	0.22 m	Grey brown silts, rare humified organics				
	0.28 m	Grey brown silts, rare humified organics				
	0.36 m	Grey brown silts, rare humified organics				
	0.44 m	Grey brown silts, rare humified organics				
	0.54 m	Brown well humified silty peat with fine sands				
	0.60 m	Brown well humified silty peat with fine sands				
	0.62 m	Grey/brown slightly organic clay				
	0.64 m	Grey/brown slightly organic clay				
	0.67 m	Blue grey clay with coarse sands				
	0.76 m	Blue grey clay with coarse sands				
	0.84 m	Blue grey clay with coarse sands				
	0.99 m	Blue grey clay with coarse sands				
	1.58 m	Brown clay above wood				
	1.61 m	Sub-fossil wood fragment				

Table 5.6.8: Samples assessed from VC16.

Depth/m	Troels Smith	Description
0-0.10	Ga2Gg(min)2	Sands with gravels
0.10–0.35	As3 Ag1 DI+	Grey silty clay with occasional humified woody fragments
0.35–0.37	Gmin3 Ag1	Sand Band (with pebbles)
0.37–0.50	Ag2 Gmin2 Ptm+ DI+	Dark grey silt with coarse gravels/shell fragments, humified wood and large flint
0.50–0.80	As3 Ag1 Gmin+	Pinky brown slightly silty clay with occasional chalky pebbles (0.60–0.62-sand band)
0.80–1.00	Gmin4 Ag+	Fine slightly silty buff sand
1.00–2.15	As3 Ag1	Dense pink-brown clay (boulder clay — possible problem with recovery)

Table 5.6.9: Sedimentary description of VC17.

Core	Depth	Sediment	Pollen	Ostracods	Bulks	Diatoms	Dates
VC17	0.16 m	Grey silty clay (woody fragments)					
	0.32 m	Grey silty clay (woody fragments)					
	0.48 m	Dark grey silt (shells, humified wood)					
	0.64 m	Silty clay					

Table 5.6.10: Samples assessed from VC17.

VC 18

Coring group:	4 (see Fig. 1 Figure 5.6.1)
Total recovery:	3.00 m
Northing:	36196.13
Easting:	5907085.69
Water depth:	26.59 m

Stratigraphy and subsampling summary (see also Plate 5.6.2)

Pollen assessment

Depth/m	Troels-Smith	Description
0-0.15	Ga2Gg(min)2	Coarse sands shells and gravels
0.15–1.00	As4 Gmin+ DI+	Grey silt with some coarse sands and occasional woody fragments
1.00–1.10	Ag3As1 Sh+ Dh+	Grey brown slightly organic clay silt with thin organic partings, organic to base
1.10–1.43	Ag2As1 Gmin1 Gmaj+ Sh+	Coarse grey brown sandy silt with rare flints and humified organic material
1.43–3.00	As3Ag1 Sh+	Stiff grey brown clay with occasional chalk gravel, charcoal fragments?

Table 5.6.11: Sedimentary description of VC18.

Four subsamples were taken from the grey silt (0.16, 0.64, 0.96 and 1.04 m) for pollen assessment (Figure 5.6.2). The sequence

is dominated by trees and shrubs over 85% with *Corylus avellana*-type recorded at 60% in each sample. *Quercus* is present at up to 10% along with *Pinus sylvestris*, although values for this species drop to 5% after 0.96 m. *Betula* and *Ulmus* are recorded up to 5% and *Alnus* (alder) is present throughout but at trace values. Poaceae is the dominant herbaceous pollen type and reaches values up to 20%. All other herbs including Cyperaceae, Caryophyllaceae (the pink family) and Chenopodiaceae (Goosefoot/Fat hen) are present at trace values only. *Sparganium* (bur-reed) is present, indicating standing or slow flowing water; however it peaks in the basal sample (1.04 m) then drops to c.25% by 0.96 m which coincides with the transition from slightly organic clayey silt to grey silt containing woody fragments. Two further samples were taken from the sandy silts with humified organics at 1.12 m and 1.28 m depths but produced no pollen. The impression is of closed hazel dominated woodland with areas of oak, elm, pine and birch. The low and sparse representation of herbs indicates that there was little open ground, with those taxa present (sedges, fat hen and pink families) probably associated with damper contexts adjacent to the sampling site.

Ostracoda and foraminifera assessment

Eight samples (0.16, 0.32, 0.64, 0.96, 1.12, 1.16, 1.28 and 1.36 m) were examined of which the lowermost four (1.12, 1.16, 1.28 and 1.36 m) were barren. The upper four samples (0.16, 0.32, 0.64, 0.96 m) contained a mix of ostracods and forams that together provide strong evidence for a brackish water habitat, especially through the presence of the euryhaline *Cyprideis torosa* and the low-brackish water species *Cytheromorpha fuscata*. The assemblage is similar to those from the modern estuaries of East Anglia, which may indicate the deposits were accumulating in a relatively protected, estuarine depositional environment.

VC 29

Coring group:	4 (see Fig. 1 Figure 5.6.1)
Total recovery:	1.81 m
Northing:	400365.25
Easting:	5909876.06
Water depth:	23.90 m

Core	Depth	Sediment	Pollen	Ostracods	Bulks	Dates
VC18	0.16 m	Grey silt (woody fragments)				
	0.32 m	Grey silt (woody fragments)				
	0.48 m	Grey silt (woody fragments)				
	0.64 m	Grey silt (woody fragments)				
	0.80 m	Grey silt (woody fragments)				
	0.96 m	Grey silt (woody fragments)				
	1.00 m	Transition to slightly organic clay silt				
	1.04 m	Slightly organic clay silt				
	1.08 m	Slightly organic clay silt				
	1.12 m	sandy silt (humified organic material)				
	1.16 m	sandy silt (humified organic material)				
	1.20 m	sandy silt (humified organic material)				
	1.28 m	sandy silt (humified organic material)				
	1.36 m	sandy silt (humified organic material)				

Table 5.6.12: Samples assessed from VC18.



Plate 5.6.2: The top of VC18 showing seabottom sands and shells unconformably overlying organic grey silts.

Stratigraphy and subsampling summary

Pollen analyses

This core was selected for further palynological analyses. Twenty three samples were taken at 0.04 m intervals (where stratigraphy allowed) between 0.74 m and 1.64 m, which concentrated on the organic silt and peat units. The results of the pollen analysis of VC 29 are presented as a pollen diagram (Figure 5.6.3). The diagram has been divided into two local pollen assemblage zones with the site prefix ‘VC 29’ which are summarised in detail in Table 5.6.14:

VC 29-1 (1.43–1.64m) *Corylus-Pinus sylvestris*

Concentration varied in this zone from good (4) to very low (1). Preservation was also generally much poorer than in the upper zone and contained corroded, degraded, crumpled and indeterminable grains.

VC 29-2 (0.75–1.43m) *Corylus-Quercus-Poaceae-Pinus*

Concentration and preservation was very good to excellent in all of the samples in this zone apart from 0.82 m and 0.90 m where pollen presence was restricted to a few grains and these 2 samples were therefore uncountable.

Ostracoda and foraminifera assessment

Fifteen samples were assessed of which the seven lowermost were barren (Table 5.6.15). The shallowest sediments (0.72 and 1.06 m) yielded similar brackish water assemblages to those described above (VC 18).

VC 29a

Coring group:	4 (see Fig. 1 Figure 5.6.1)
Total recovery:	3.48 m
Northing:	400350.08
Easting:	5909886.03
Water depth:	24.0 m
Stratigraphy:	29a

Pollen assessment

Core 29a was a duplicate of 29, but the recovered depth of sediment was greater. A further pollen spot sample was taken from the grey brown organic lens (2.10–2.15 m) which was not recovered in the original core. The sample (2.12 m) yielded a medium concentration and low preservation but sufficient for a reliable assessment. The dominant species recorded were Cyperaceae (sedges) (40%), *Corylus* (31%) and *Pinus* (17%). Other trees, shrubs and herbs were rare and included *Betula*, *Calluna* (heather) and *Poaceae*. A single Pre-Quaternary spore (PQS) was recorded along with a high count of Pteropsida. The presence of the PQS and enhanced values for the highly robust spores of Pteropsida may also indicate that the sample has been affected by re-working/differential preservation.

VC 29a: plant macrofossil assessment

Two bulk samples were analysed from the grey organic silts (1.42–1.85 and 1.85–2.10 m). The lowermost sample (1.85–2.10 m) contained the widest species range, including evidence for woodland in the form of hazelnuts (*Corylus avellana*) and the cupules from acorns (*Quercus* sp.) although post depositional erosion precluded identification to species. The hazelnuts recovered from this sample included whole examples and probably represent fallen nuts within litter deposits, confirming the local presence of this species indicated by the pollen record.

This sample also contained macrofossils of the herbs gypsywort and sedges (*Lycopus europaeus* and *Carex* spp.) suggesting damp conditions, alongside wild celery (*Apium graveolens*), which is found in brackish places and stinking goosefoot (*Chenopodium vulvaria*) that grows in brackish places near the sea. The overlying sample (1.42–1.85 m) contained seeds from downy birch (*Betula pubescens*) together with common reed, club rushes and sedges (*Phragmites australis*, *Schoenoplectus* and *Carex* spp.). The presence of rushes and reeds probably reflects the presence of reedswamp growing on and around the sampling site. Birch seeds can be readily distributed by wind/water and their presence in this sample may not necessarily reflect local birch trees.

Beetle assessment

The three insect faunas recovered from the different depths in the core are very similar. They are all dominated by a range of small

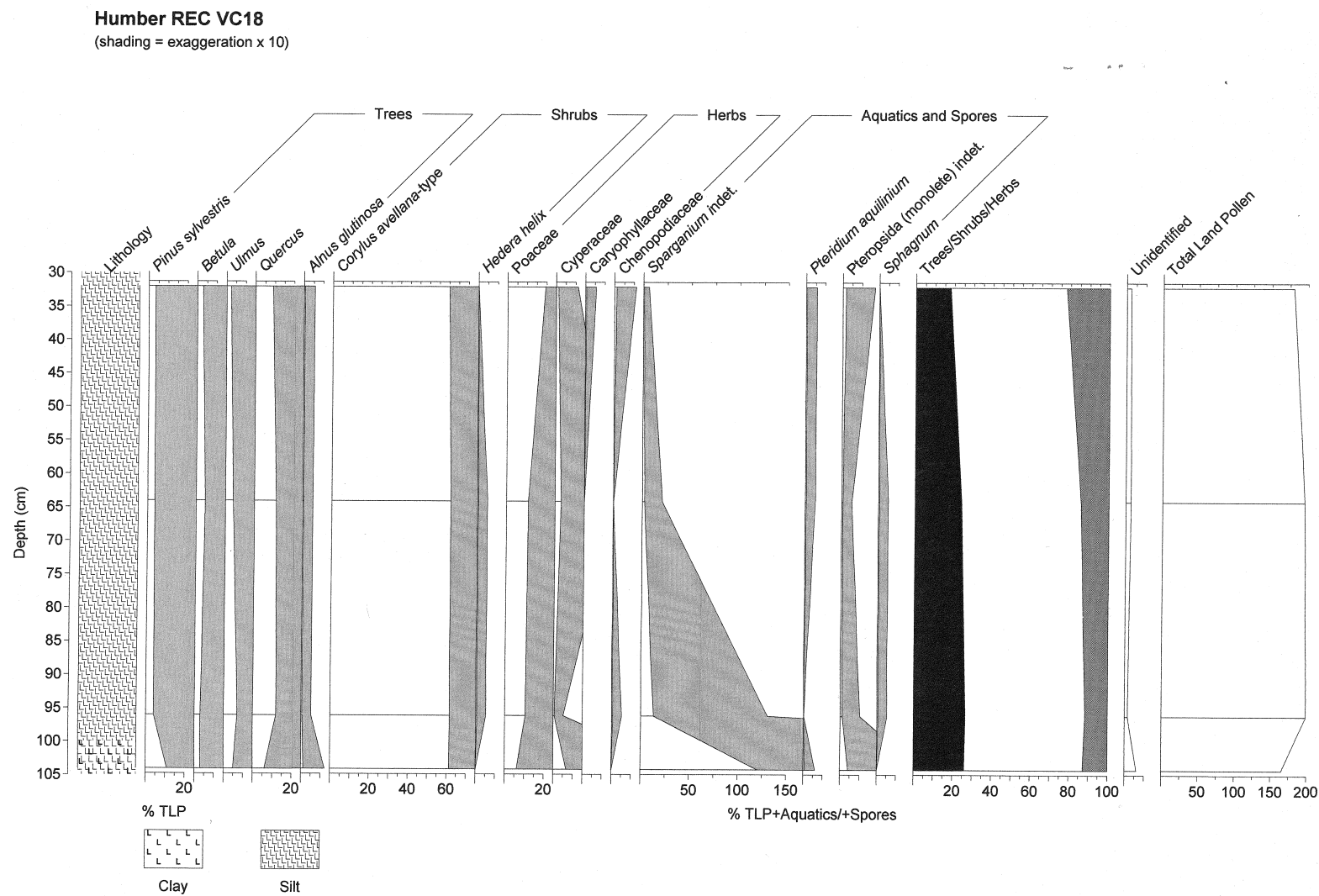


Figure 5.6.2: VC18 pollen assessment.

Depth/m	Troels-Smith	Description
0–0.50	Gmin2 Gmaj2 Ptm++	Shell rich coarse sands and gravels
0.50–0.75	Gmin3 Ag1	Grey medium coarse shelly sands with occasional flints
0.75–1.36	Ag3 As1 Dg+	Grey clayey silt, black mottled humified organic fragments
1.36–1.44	Sh2 Ag1 Dg1	Black brown well humified silty peat with wood fragments
1.44–1.60	Ag3 Sh1 As+	Grey brown organic silt with humified organic detritus
1.60–1.81	Gmin4 Ag+	Grey medium coarse sands slightly silty with chalky gravels to base

Table 5.6.13: Sedimentary description of VC29.

water beetles that are usually associated with slow flowing or still water in bogs and river channels. Taxa typical of such habitats include *Hydraena* spp., *Ochthebius* spp., *Cercyon tristis* and *Cymbiodyta marginella* (Hansen 1987). The small weevil *Bagous* spp. is often also associated with such water conditions. The presence of the 'reed beetle' *Plateumaris braccata* suggests that stands of common reed (*Phragmites australis*.) were present on and around the sampling site. Equally, duck weed (*Lemna* spp.) appears to have been growing in the areas of open water since this is the host plant of *Tanysphyrus lemnae* (Koch 1992).

There are indications that mature woodland was present in the vicinity. The eucnemid *Melasis buprestoides* is often associated

with deadwood in the branches of a range of deciduous trees. Similarly the weevil *Curculio* spp. (the 'nut weevil') bores into a range of nuts associated with trees, as do the larvae of *Rhynchities* spp. (Koch 1992). Unfortunately, it was not possible to identify these latter two taxa to species level, which would have allowed identification of the specific range of trees present. There is also limited evidence that herbivores may have grazed in the woodland, with the presence of the *Aphodius* 'dung beetles' in the lower parts of the sequence. These beetles are only associated with the dung of grazing animals in relatively open conditions (Jessop 1986).

VC 29b

Coring group: 4 (see Fig. 1 Figure 5.6.1)
Total recovery: 2.96 m
Northing: 400350.08
Easting: 5909886.03
Water depth: 24.0 m
Stratigraphy: 29b

VC 29b: Pollen analyses

VC 29b was a second duplicate of VC 29. Thirty one samples for pollen analyses were taken at 0.04 m intervals (where stratigraphy allowed) between 0.73 m and 2.02 m, which concentrated on the organic silt, peat and organic silty clay units. The results are presented as a pollen diagram (Figure 5.6.4). The 16 basal samples (from the lower organic silty clay layer and the basal fine silty sands; 1.32–2.02 m) produced either very low pollen concentrations or pollen was completely absent; hence these have not been included in the pollen diagram. Concentration varied throughout the pollen diagram from low (1) to good (4), with 3 samples (0.96 m, 1.04 m and 1.20 m) producing extremely low to absent counts and these samples were therefore omitted from the diagram. Preservation was generally poor with the majority of the samples scoring between very poor (-1) to medium (3).

Plant macrofossils

Following sub-sampling for OSL dating and pollen analyses, the remaining sediment was bulked into six samples for plant macrofossil and beetle analyses. The results of the plant macrofossil analyses were as follows:

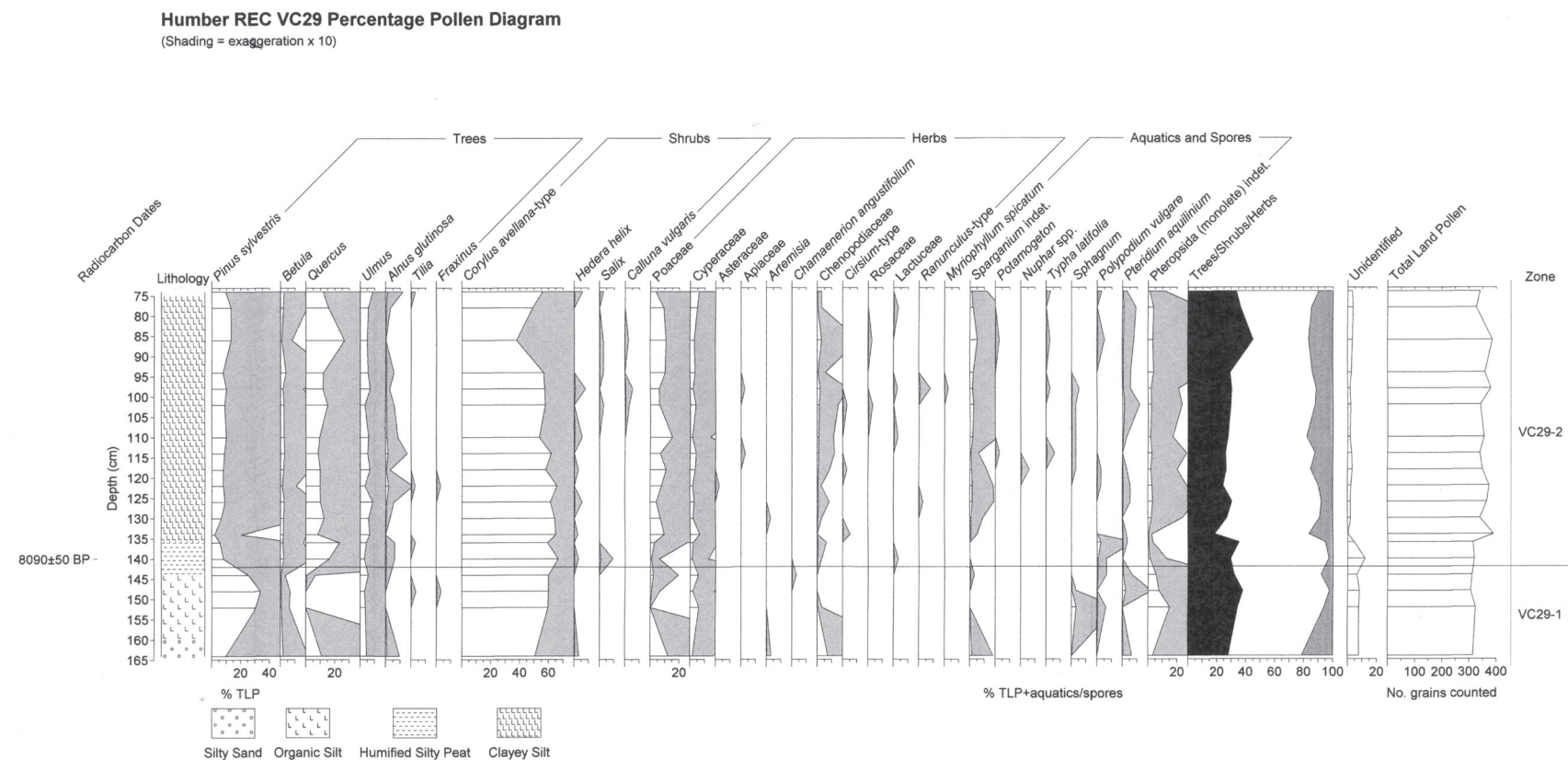


Figure 5.6.3: VC 29 pollen diagram.

1.90–2.0 m: Apart from a little very decayed herbaceous detritus, perhaps including roots/rootlets there were no interpretatively useful plant remains, consistent with this being basal, almost sterile, drift.

1.50–1.76m: There were a few small very decayed rootlets and a few *Cenococcum sclerotia* perhaps pointing to inwash of soil.

1.24–1.50m: The presence of abundant remains of oak (buds, bud-scales, cupule fragments), together with wild plum/bullace, a few fragments of hazel nutshell and at least one fruitstone of dogwood indicate material from a mature oak forest, and the small assemblage of mosses was consistent with this. The results echo those for Core 29 (see above). The abundant sclerotia of *Cenococcum* presumably reflect inwash of forest soil rather than *in situ* peat formation. The squashed character of the acorn cupules leads to the suggestion that these were reworked from a deposit which had formed some considerable time previously and had become compressed under a weight of later sediment.

0.98–1.24 m: The substantial fragment of wood (and other wood fragments), together with oak bud-scales and woodland mosses again point to inwash of woodland soil, though here *Cenococcum sclerotia* were not noted. The presence of some substantial rhizome fragments perhaps suggests growth of reed/reedmace swamp in the channel.

0.72–0.98 m: The rhizome fragments seen in 0.98–1.24 m were again frequent here but small numbers of oak bud-scales continue to indicate a terrestrial component from forest somewhere in the catchment.

Ostracoda and foraminifera assessment

Five samples were assessed (0.74, 1.06, 1.22, 1.4 and 1.52 m) of which the two lowermost were barren (Table 5.6.17). The shallowest sediments (0.74 and 1.06 m) yielded similar brackish water assemblages to those described above (VC 18). However, the absence of *C. fuscata* and the rare presence of saltmarsh

foraminifera (1.06 and 1.22 m) suggest somewhat greater marine influence and proximity to intertidal saltmarsh environments.

Chronology

A radiocarbon date of 8090 ± 50 BP (Beta-260805, Cal BC 7180 to 7030) was obtained on a sample of sub-fossil wood (1.40m) from the humified peats (1.36–1.44 m). Six OSL dates were also obtained on sub-samples from this core (see Plate above). Two dates from the dense basal clay (1.98–2.04 m and 1.84–1.90 m) produced estimates of 27 ± 2 Ka and 23 ± 2 Ka (GL-09066 and 09065), indicating these clays were deposited during the Devensian glaciation. The overlying silty clays (1.52–1.58 m) produced a date of 12.9 ± 1.2 Ka (GL-9064) suggesting deposition most probably during the late-glacial period. A sample from the organic silts overlying the peat unit (see above) yielded an estimate of 8.0 ± 0.9 Ka (GL-09063), confirming that the silts were deposited during the early Holocene. Two further dates from the middle (0.89–0.99 m) and top (0.59–0.69 m) of the silt unit produced estimates of 5.9 ± 0.4 Ka (GL-09062) and 6.5 ± 0.5 Ka (GL-09061) providing a chronology for these sediments. The chronological model (Figure 5.6.5) and associated posterior density estimates derived from this model are presented in Table 5.6.18.

VC 39

Coring group:	8 (see Fig. 1 Figure 5.6.1)
Total recovery:	2.0 m
Northing:	421154.41
Easting:	5973114.32
Water depth:	31.68 m

Stratigraphy and subsampling summary

Ostracoda and foraminifera assessment

The three samples recovered from this core (1.16 m, 1.32 and 1.64 m) all contained assemblages that suggested euryhaline-brackish salinities and the influence of both upper and lower saltmarsh. The lowermost sample (1.64 m) included a number of rare occurrences of open marine ostracods. This probably reflects taxa that have been redeposited at the sampling location during a phase of increased marine influence, but the precise timing and nature of any such event is unclear on the basis of the current data.

Zone/Depth	Strat	Main characteristics	Interpretation
VC29–1	Silty sand	<p><i>Corylus-Pinus</i></p> <p>Tree and shrub pollen dominate this zone between 80–98%. <i>Corylus</i> accounts for up to 60% and <i>Pinus</i> up to 30%. <i>Quercus</i> is recorded at 10% in the basal sample but is then absent throughout the rest of the zone. <i>Ulmus</i> is recorded at low but consistent values <5% and <i>Betula</i> at trace values. All other trees and shrubs are rare, but include occasional grains of <i>Alnus glutinosa</i>, <i>Tilia</i>, <i>Fraxinus</i> and <i>Hedera helix</i>. Herbaceous pollen is recorded up to 20% at the opening of the zone which largely consists of Poaceae (10%) and Chenopodiaceae (<10%) which both decline to trace values by the top of the zone. Cyperaceae is recorded at low values <5% along with single grains of <i>Artemisia</i> and <i>Chamaenerion angustifolium</i>.</p> <p>Aquatics are rare apart from occasional grains of <i>Sparganium</i>. Pteropsida attains its highest values in this zone (up to 15%TLP+spores). Other spores include <i>Sphagnum</i>, <i>Polypodium vulgare</i> and <i>Pteridium aquilinum</i> all present at low values <5%.</p>	Dense mixed hazel and pine woodland. With some small open areas and a possible indication of salt marsh environments from the presence of Chenopodiaceae (fat hen).
1.65–1.43 m	Organic silt		
1.40 m		Radiocarbon date: 8090 ± 50 BP	
		<p><i>Corylus-Quercus-Poaceae-Pinus</i></p> <p>Tree and shrub pollen dominate this zone between 80–98%. <i>Corylus</i> accounts for up to 65%. <i>Quercus</i> increases from trace values to 20% in the opening of this zone and maintains values between 10–20% throughout. <i>Pinus</i> declines rapidly in the opening of this zone to values <15%. <i>Betula</i> and <i>Ulmus</i> maintain low but consistent values <10%. <i>Alnus</i> is recorded at trace values throughout along with occasional grains of <i>Alnus</i>, <i>Tilia</i>, <i>Fraxinus</i>, <i>Hedera helix</i>, <i>Salix</i> and <i>Calluna vulgaris</i>. Herbaceous pollen increases slightly in this zone and largely consists of Poaceae (up to 15%), Cyperaceae (c.5%) and Chenopodiaceae (<5%). Other herbs are rare and include occasional grains of Asteraceae, Apiaceae, <i>Artemisia</i>, <i>Cirsium</i>-type, Rosaceae, Lactuceae and <i>Ranunculus</i>-type.</p> <p><i>Sparganium</i> increases to up 5%TLP+aquatics along with occasional grains of <i>Potamogeton</i>, <i>Nuphar</i> spp. and <i>Typha latifolia</i>. Pteropsida decreases to values <5%TLP+spores. <i>Sphagnum</i>, <i>Polypodium vulgare</i> and <i>Pteridium aquilinum</i> are present at trace values.</p>	Dense mixed hazel and oak woodland with a slight increase in small open grassy areas and evidence for shallow water.
VC29–2			
0.75–1.43 m	Humified silty peat		

Table 5.6.14: Summary of VC29 pollen diagram by zone. All values are %TLP (Total Land Pollen).

Chronology

Four OSL dates were obtained on this core which produced estimates of 10.5 ± 1.4 Ka (0.45–0.55 m, GI-9067), and 9.6 ± 0.8 Ka (1.02–1.10 m, GI-9068), 9.3 ± 0.8 Ka (1.44–1.54 m, GI-9069) and 8.6 ± 0.7 Ka (2.16–2.26 m, GI-9070). The chronological model and associated posterior density estimates derived from this model are presented in Figure 5.6.6 and Table 5.6.21.

VC 47 and 47a

Coring group: 2 (see Fig. 1 Figure 5.6.1)
 Total recovery: 3.84, 4.07 m
 Northing: 5939243.15
 Easting: 357862.35
 Water depth: 30.7 m

Stratigraphy (47)

Stratigraphy (47a)

OSL dating was carried out on five samples from VC 47a (see above). However, only one of the dates (0.32 ± 0.04 yr Ka, GL09072, 0.58–0.66 m) can be accepted, with the remaining four dates (GL09071, 09073, 09074 and 09075) affected by analytical problems. The accepted date of 0.32 ± 0.04 yr Ka (GL09072) indicates a later Holocene timeframe for the deposition of the upper marine sand unit (0–2.0 m), with the two tentative dates of 0.86 ± 0.09 yr Ka (0.99–1.10 m, GL09073) and 0.11 ± 0.02 yr Ka (0.30–0.40 m, GL09071) also in line with this estimate. The date of 33 ± 7 yr Ka (2.25–2.35 m, GL09074) has been rejected and the basal date 19 ± 7 yr Ka (3.95–4.05 m, GL09075) regarded as a maximum age estimate only. These issues meant that the chronological sequence could not be robustly modelled using a Bayesian approach (Figure 5.6.7).

VC 48 (Plates 5.6.3 and 5.6.4)

Coring group: 4 (see Fig. 1 Figure 5.6.1)
 Total recovery: 1.88 m
 Northing: 368746.00
 Easting: 5906848.36
 Water depth: 27.5 m

Stratigraphy and subsampling summary

Pollen assessment

This sequence was selected for further pollen analyses and 13 samples were taken at 0.08 m intervals (where stratigraphy allowed) between 0.24–1.30 m. The results of the pollen analysis of VC 48 are presented as a pollen diagram (Figure 5.6.8). The basal sample (1.30 m) produced the lowest concentration (1) and poorest preservation (1) which was taken from the peaty silt layer and only an assessment count was obtained. Concentration and preservation increased rapidly from good (4) to excellent (5) throughout the rest of the diagram where all the samples were taken from the weakly laminated grey silt layer.

Depth/m	Troels Smith	Description
0–0.40	Gmin4	Medium coarse sands
0.40–0.70	Gmin3 Ag1 Ptm+	Grey slightly silty sand with shell fragments (0.66m–thin organic lens 3–4 mm)
0.70–1.00	As2 Ag2 Dg+	Grey silty clay with occasional humified organics
1.00–1.85	Ag3 As1	Grey clayey silts
1.85–2.00	Sh2 Ag2	Silty peat
2.00–2.10	Ag3 As1	Grey clayey silts
2.10–2.15	As3 Dg1	Grey brown organic clay lense
2.15–2.45	Gmaj2 Gmin2 As+	Grey coarse gravelly sand, slightly clayey with pebbles
2.45–3.48	As4 Ag+	Grey clay with chalk fragments, slightly silty

Table 5.6.16: Sedimentary description of VC29a.

Depth/m	Troels Smith	Description
0.19–0.38	Gmin3 Gmaj+ ptm1	Buff coarse shelly sand
0.38–0.53	Gmin2 Gmaj1ptm1	Dark brown coarse shelly sand
0.53–0.72	Gmin2 Gmaj+ Ag+ ptm1	Grey shelly sand, occasional silt
0.72–1.24	Ag3 Dg1 As+	Smooth grey silt clay, occ organics, weakly laminated
1.24–1.31	Dg1 Ag2 As1 Ga+	Black well humified peat, woody at top
1.31–1.76	Dg1 Sh3 Ag +	Black brown organic silt clay
1.76–2.03	Ag1Ga1 Gmin1 Gmaj+	Fine silty grey sand, siltier at base
2.03–2.96	Gmin2 Gmaj1 Ag+	Brown red sand with pebbles

Table 5.6.17: Sedimentary description of VC29b.

Plant macrofossils

1.32–1.60 m: This basal sample contained a notable charred component with charred *Cenococcum* sclerotia and a little wood charcoal. Much of the other plant material consisted of rhizome and root fragments but with a small terrestrial (woodland) component of hazelnut and dogwood fruits.

0.98–1.28 m: The plant material was largely compressed ‘stiff’ rhizome fragments, the modest range of fruits and seeds indicating a marsh or reedswamp environment, perhaps with some marine influence.

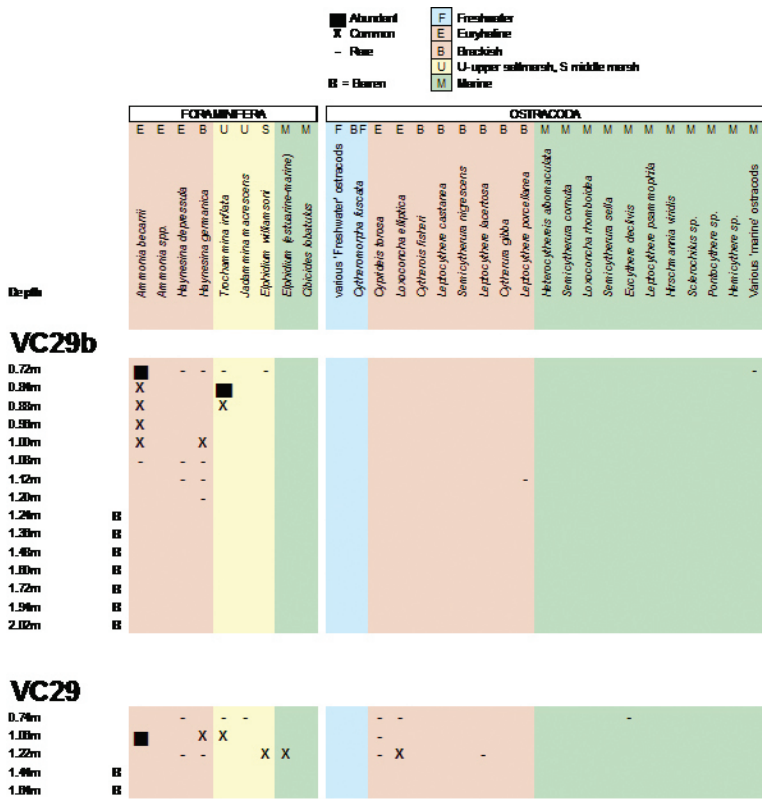


Table 5.6.15: Ostracod and foraminifera analysis of VC 29 and 29b.

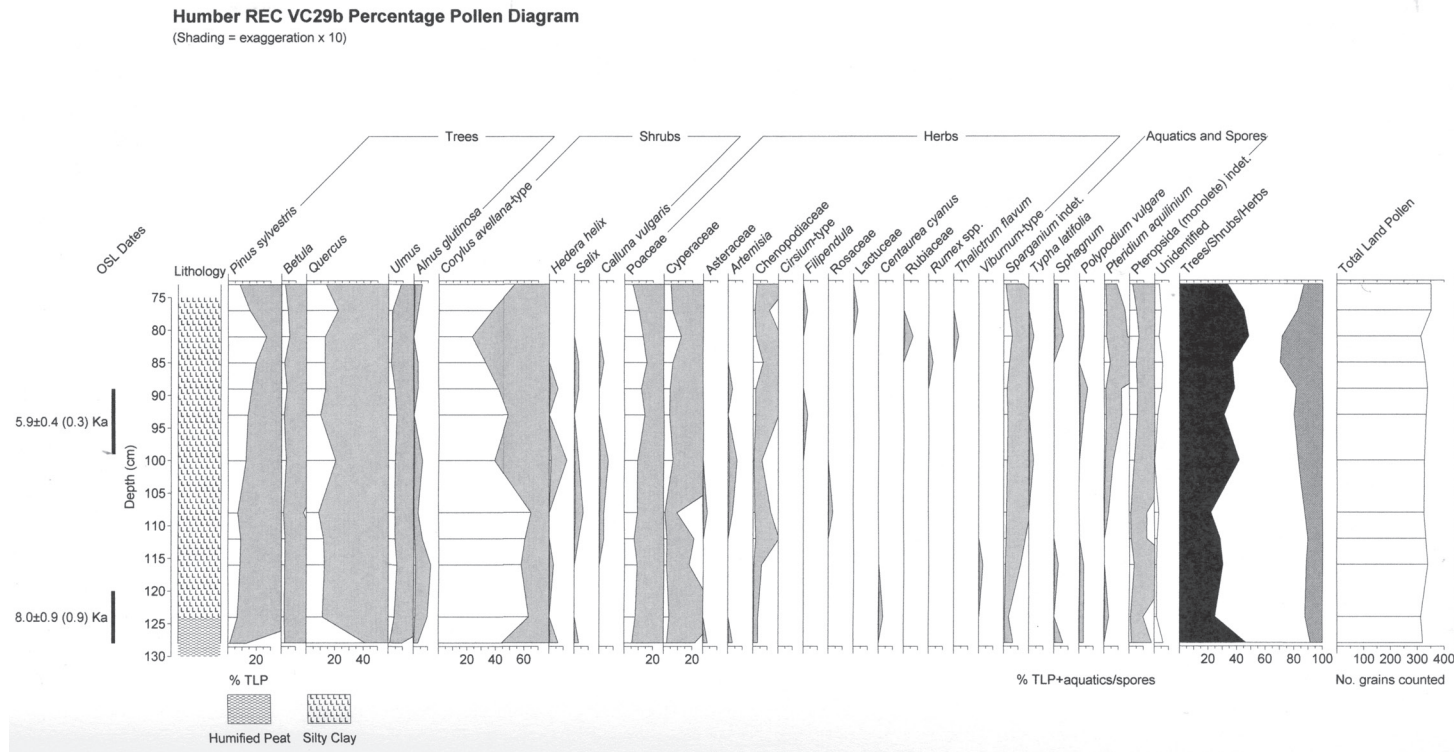


Figure 5.6.4: VC29b pollen diagram.

0.64–0.94 m: Much of the plant material comprised rhizome fragments of both flimsy and more rigid character. The traces of stonewort oogonia and horned pondweed fruits are consistent with an open freshwater environment.

0.28–0.60 m: The ‘stiff’ rhizome fragments seen in parts of Core 29b were again present here and the small assemblage of fruits and seeds were all from plants likely to have grown in freshwater fen or marsh (though with the admixture of marine shell).

Ostracoda and foraminifera assessment

Eight samples were assessed (0.40, 0.72, 0.94, 1.10, 1.26, 1.30, 1.34 and 1.60 m) but that from 1.10 m and the lowermost three samples (1.30, 1.34 and 1.60 m) were barren. The microfossils from the other samples were dominated by species that can be assigned to euryhaline habitats with significant occurrences of freshwater and low-brackish water ostracod taxa. These suggest a rather restricted, low salinity-brackish habitat with some salinity fluctuation but no evidence of a strong, open marine connection. The influence of freshwater appears to weaken towards the top of the sequence.

Date-code	68% probability	95% probability
GL09066	25810–22050 BC	27760–20300 BC
GL09065	22430–18810 BC	24050–16900 BC
GL09064	12090–9690 BC	13280–8500 BC
Beta-260805	7180–7030 cal BC	7300–6820 BC
GL09063	6720–5270 BC	7070–4630 BC
GL09062	4600–3940 BC	4940–3620 BC
GL09061	4330–3610 BC	4660–3230 BC

Table 5.6.18: VC29 posterior density estimates.

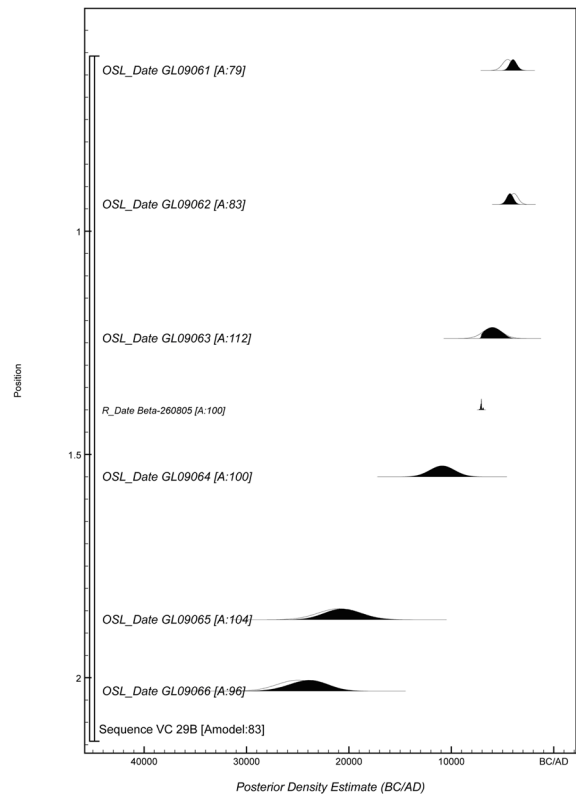


Figure 5.6.5: VC 29b chronological model.

Diatom analyses

Eleven samples were analysed (see Table 5.6.25) although diatoms were not abundant, hence full counts were not attempted. The diatom floras had undergone degradation to some degree making identification of several taxa impossible. The lowest sample examined contained only a fragmentary fauna, possibly due to higher turbidity. Diatoms were rare or very rare at 1.22–1.14, 0.88, 0.68, 0.44 and 0.24 m depth, but more numerous in the

intervening samples, perhaps as a result of cyclic environmental or sedimentological variability. Although freshwater species were not found, several brackish water species were present, including frequent *Epithemia adnata*, together with less common species of *Surirella*, *Navicula*, *Nitzschia* and *Caloneis*. *Melosira* varians, a brackish water species that is often found in estuaries around Britain and usually associated with firm surfaces, is consistently present and one of the more numerous species in the borehole. Brackish taxa are accompanied by diatoms such as *Biddulphia*, *Roperia*, *Actinopterychus*, *Coscinodiscus* and *Gyrosigma* which are shallow marine taxa. The microfloras therefore appear to represent outer estuarine to shallow marine environments throughout the borehole, hence in broad agreement with the results of the ostracod/foram assessments.

Depth/m	Troels-Smith	Description
0–1.00	Gmin3 Gmaj1	Coarse orange shell rich sands with gravels
1.00–1.25	Ag3 Gmin1	Grey silt with very fine sands, black mottled
1.25–1.34	Ag4	Grey black mottled silt
1.34–2.00	As3 Ag1	Red brown clay (boulder)

Table 5.6.19: Sedimentary description of VC39.

Core	Depth	Sediment	Pollen	Ostracods	Bulks	Diatoms	Dates
VC39	0.45 m	grey silt					
	1.00 m	grey silt					
	1.16 m	grey silt					
	1.32 m	grey black mottled silt					
	1.48 m	boulder clay					
	1.64 m	boulder clay					

Table 5.6.20: Samples assessed from VC39.

Radiocarbon date

A radiocarbon date of 8060 ± 50 BP (Beta-260806, Cal BC 7130 to 7100) was obtained from a fragment of sub-fossil wood from a depth of 1.30 m, close to the base of the grey-brown mottled peaty silt unit (1.36–1.44 m).

Date-code	68% probability	95% probability
GL09070	7800–6980 BC	8230–6580 BC
GL09069	7650–6860 BC	8030–6480 BC
GL09068	7530–6710 BC	7920–6280 BC
GL09067	7460–6510 BC	7890–5880 BC

Table 5.6.21: VC39 posterior density estimates.

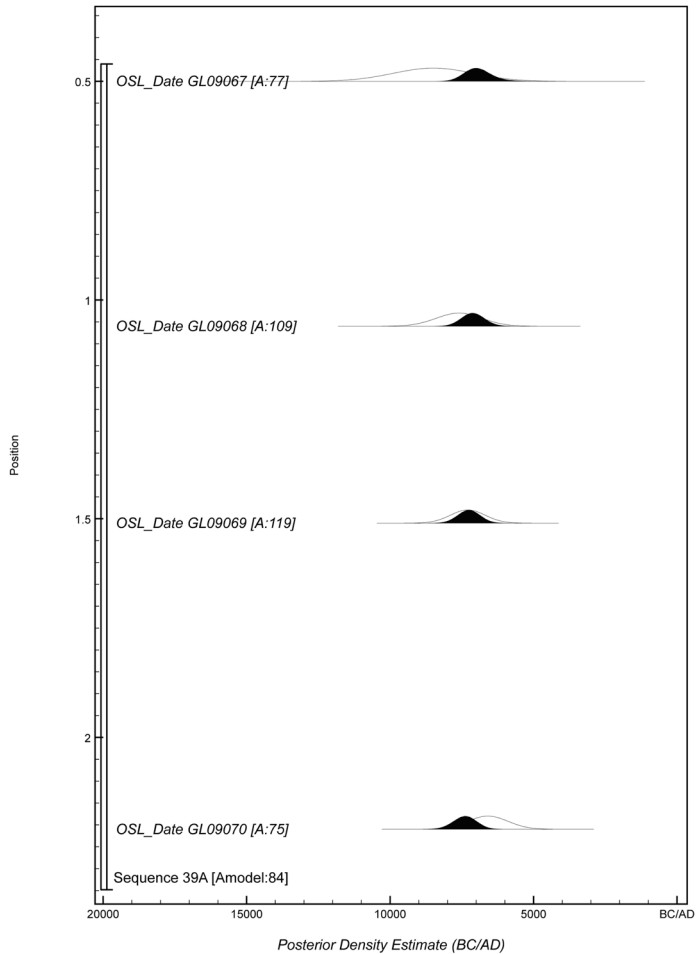


Figure 5.6.6: VC 39 chronological model.

VC 48a

Coring group:	4 (see Fig. 1 Figure 5.6.1)
Total recovery:	2.88 m
Northing:	368758.16
Easting:	5906853.72
Water depth:	27.0 m

Depth/m	Troels Smith	Description
0–1.10	Gmin2 Gmaj2	Beige coarse sands, some shells and gravels
1.10–2.32	Gmaj2 Gmin1 Ptm1	Sand becoming gravel and shell rich
2.32–3.84	Gmin4	Beige fine sand with coarse shelly sands, occasional black partings

Table 5.6.22: Sedimentary description of VC47.

Depth/m	Troels Smith	Description
0–2.00	Gmin2 Gmaj2 ptm++	Shell rich coarse sand
2.00–3.30	Gmin3 Ag1	Weakly laminated soft buff sand, charcoal in the laminations, wood at 3.17 m
3.30–3.31	Ag3 Ga1	Grey green silt, sharp upper and lower transition
3.31–3.81	Gmin3 Ag1	Laminated buff sand with charcoal laminations
3.81–3.82	Ag3 As+	Grey green silt clay, occasional charcoal, wood @ 3.83, just below transition
3.82–4.07	Gmin2 Gmaj1	Soft buff sand, weakly laminated, wood @ 3.94, darker at base

Table 5.6.23: Sedimentary description of VC47a.

Stratigraphy and subsampling summary

Plant macrofossil assessment

Four bulk samples from this core were assessed for plant macrofossils and insects (0–0.45, 0.45–1.0, 1.0–1.25 and 1.25–1.50 m). A restricted range of plant remains were recorded in the uppermost sample (0–0.45 m) and included taxa such as grass and common reed (*Poa* sp. and *Phragmites australis*) Sample 0.45–1.00 contained common reed, sedges and small pondweed (*Phragmites australis* (Cav.) Trin. ex Steud, *Carex* sp. and *Potamogeton berchtoldi* Fieber). Whilst that from 1.00–1.45m contained the same range of taxa as the previous sample with the addition of club rush (*Schoenoplectus*). Finally, depth 1.25–1.50 contained only common reed and sedges (*Phragmites australis* and *Carex* sp.).

Beetle assessment

The four faunas recovered from Core 48a produced a similar range of water beetles to those recorded in Core 29a and usually

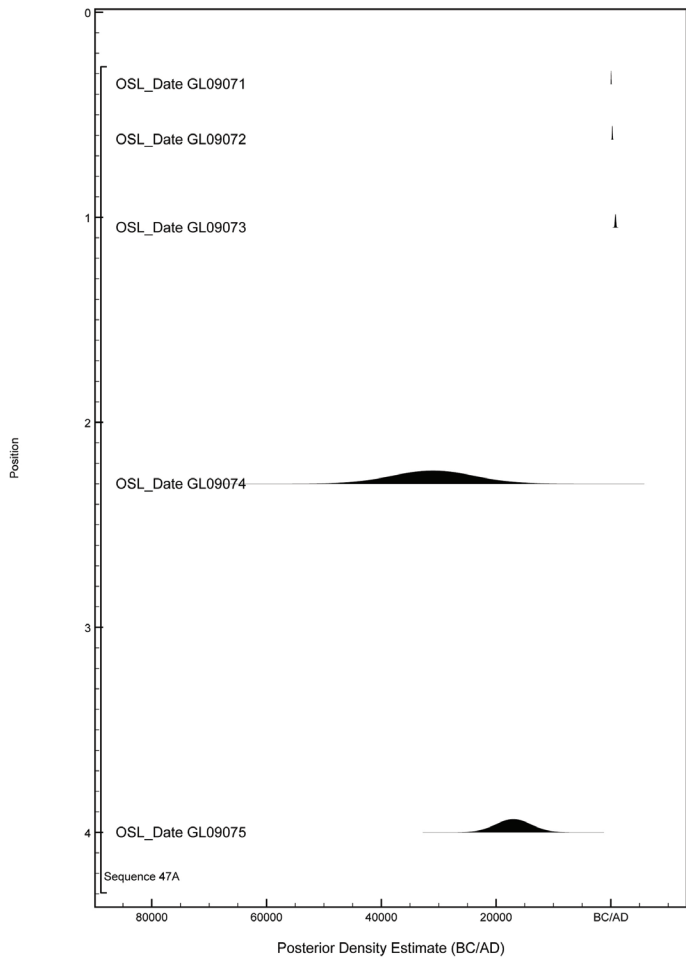


Figure 5.6.7: VC 47a chronological model.

associated with slow flowing or still water in river channels. Taxa typical of such habitats include *Hydraena* spp., *Ochthebius* spp., *Cercyon tristis* and *Cymbiodyta marginella* (Hansen 1987). Other indicators of the local environment include specimens of *Plateumaris braccata*, which is associated with *Phragmites communis* (common reed). There is also evidence for a rich aquatic plant community which included sweet grasses (*Glyceria* spp. — the host plant of *Donacia semicuprea*), bulrush (*Typha* spp. — the host plant of *Donacia cinerea*), rushes and sedges (*Juncaceae* and *Cyperaceae* — the host plant of *Limnobaris pilistriata*). Significantly, there are indications of the wider environment probably beyond the wetland area. Mature woodland/deadwood was present in the vicinity as suggested by the recovery of the *Curclio* spp. ‘nut weevil’ (Sample 1.25–1.50 m) and the *dermestid*

Depth/m	Troels Smith	Description
0–0.10	Gmin2 Gmaj2	Shelly sands
0.10–1.28	As4 Gmin DI+ Dh+	Grey silt with coarse sands occasional woody frags/monocots, weakly laminated
1.28–1.34	Ag2 Sh1 Dg1 DI+	Grey brown mottled peaty silt, organic detritus/wood fragments and monocots
1.34–1.60	Gmin2 As1 Ag1 Dg+	Grey brown clayey sand, coarse sand and occasional humified organic remains
1.60–1.88	As3Ag1	Stiff grey brown clay with occasional chalk gravel

Table 5.6.24: Sedimentary description of VC48.



Plate 5.6.3: The peaty silt unit (VC48: 1.28–1.34 m).

Megatoma undata (Sample 1.0–1.25 m). The latter species is often associated with deadwood and/or found under the bark of a range of deciduous trees, where it feeds on the detritus left by wood boring insects (Hymen and Parsons 1992).

VC 49

Coring group:	4 (see Fig. 1 Figure 5.6.1)
Total recovery:	1.83 m
Northing:	369207.48
Easting:	590697.43
Water depth:	26.7 m



Plate 5.6.4: Grey silts (0.10–1.28 m) in VC48 showing weak laminations and plant fragments.

Stratigraphy

Pollen assessment

Core 49 consisted of largely minerogenic deposits apart from two thin organic layers between 0.14–0.30 m and a well humified peat between 0.30–0.36 m. Samples were taken from 0.14 m and 0.31 m in VC 49. The latter sample yielded a medium concentration and low preservation of pollen but an assessment count was obtained. This sample was dominated by *Corylus*, *Quercus*, Poaceae and Cyperaceae, but aquatics in the form of *Sparganium* and *Potamogeton* (pond weed) were very abundant, suggesting extensive areas of water on or close to the sampling site. High counts for the spore Pteropsida may also indicate that the pollen record has been affected by differential preservation perhaps accounting for the relatively low concentrations of somewhat poorly

preserved pollen. However, the uppermost sample demonstrated excellent concentration and good preservation. The spectrum was dominated by *Corylus* (56%), with *Quercus*, *Ulmus* and *Pinus* also recorded. Other trees and shrubs were rare but include *Betula*, *Alnus*, *Calluna* and *Salix*. Poaceae was the dominant herb along with a single grain of Cyperaceae.

VC 50

Coring group:	4 (see Fig. 1 Figure 5.6.1)
Total recovery:	4.40 m
Northing:	369219.50
Easting:	5907085.59
Water depth:	25.60 m

Stratigraphy and subsampling summary

Pollen assessment

Seven subsamples were assessed (0.50, 0.98, 1.30, 1.62, 2.08, 2.34 and 2.44 m) through the basal peaty silt and the overlying organic clayey silt. The results are presented as a pollen diagram (Figure 5.6.9). *Corylus* dominates although there is a marked increase in *Quercus* from 2.40 m as well as a small increase in *Ulmus*. The expansion of these trees appears to be at the expense of *Pinus* which has decreased from 15% to 5% by 2.35 m. Herbs including Poaceae, Cyperaceae and *Potentilla* (tormentil) are rare. The top of this segment at 2.34 m sees a shift from peaty silts to weakly laminated shell rich silts.

The pollen spectra remain fairly constant between 2.34–0.50 m with *Corylus* dominating up to 70%. Percentages of *Betula* increase at 2.30 m to values of <5% along with *Pinus*, *Quercus* and *Ulmus* also recorded at values up to 20%. Poaceae is the dominant herb which maintains low but consistent values <10%. Other herbs are rare but include occasional grains of Cyperaceae, *Artemisia*-type (mugwort), Asteraceae (daisies, thistles etc.), Caryophyllaceae (the pink family), Chenopodiaceae, *Filipendula* (meadowsweet), *Potentilla* and *Rosaceae* (the rose family).

The environment indicated throughout this core was mixed hazel dominated woodland, but with oak and elm also significant and some stands of birch and pine. There is possible evidence for restricted open areas in the woodland with grasses and sedges, although such vegetation could also be found on areas of higher soil moisture

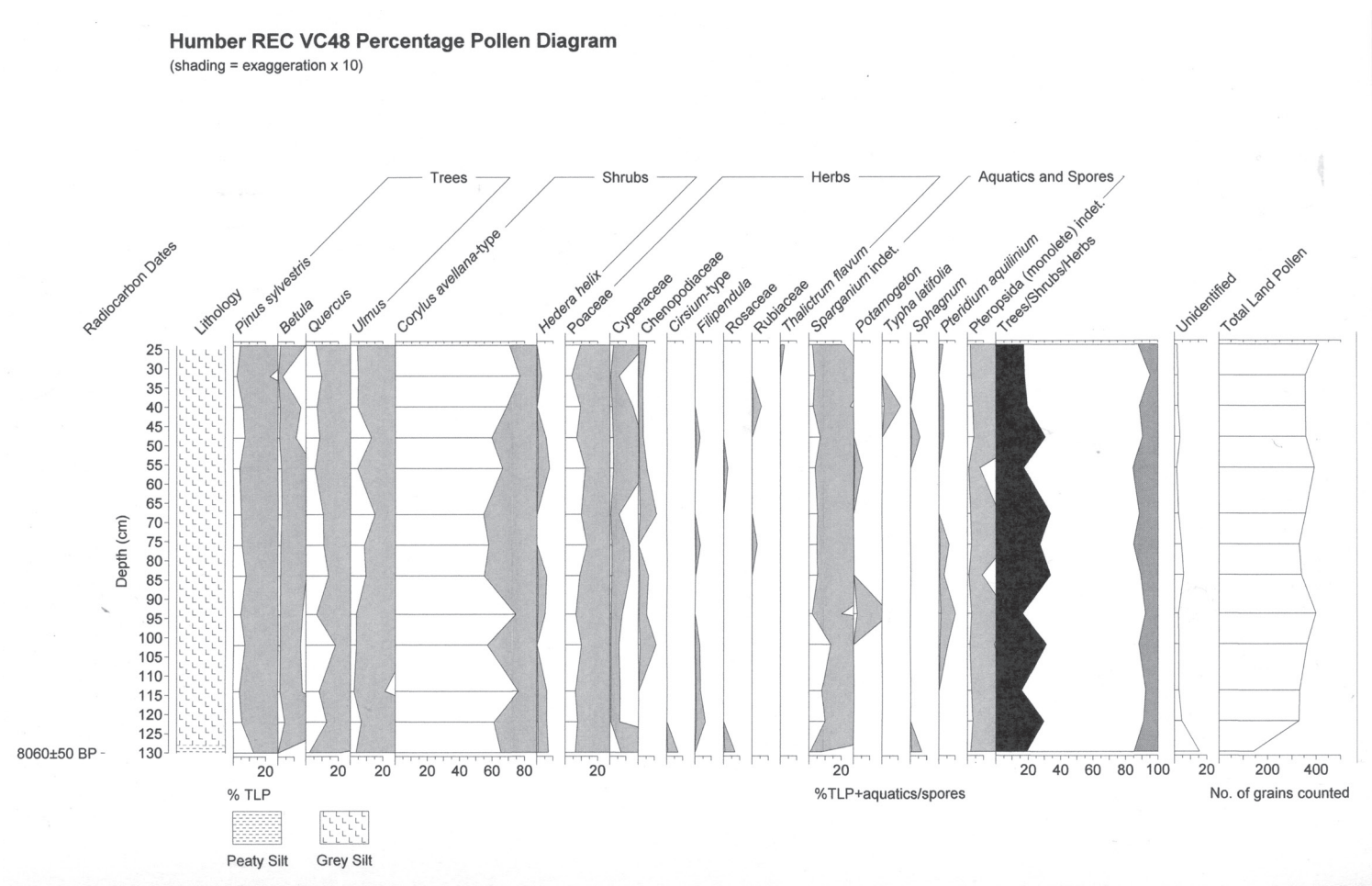


Figure 5.6.8: VC48 pollen diagram.

adjacent or at the edges of the palaeochannel. The presence of *Sparganium* and *Potamogeton* indicates standing or slow flowing water; again most probably on the sampling site itself. *Filipendula*, which appears towards the top of the sequence, is also an herb often found on damp soils and often in alder carr environments although percentages of *Alnus* do not suggest this tree was prevalent locally.

Depth/m	Troels Smith	Description
0–0.10	Gmin2 Gmaj2	Shelly sands
0.10–1.28	As4 Gmin DI+ Dh+	Grey silt with coarse sands occasional woody frags/monocots, weakly laminated
1.28–1.34	Ag2 Sh1 Dg1 DI+	Grey brown mottled peaty silt, organic detritus/wood fragments and monocots
1.34–1.60	Gmin2 As1 Ag1 Dg+	Grey brown clayey sand, coarse sand and occasional humified organic remains
1.60–2.88	As3Ag1	Stiff grey brown clay with occasional chalk gravel

Table 5.6.25: Sedimentary description of VC48a.

Core	Depth	Sediment	Pollen	Ostracods	Bulks
VC48a	0.00–0.45 m				
	0.45–1.00 m				
	1.00–1.25 m				
	1.25–1.50 m				

Table 5.6.26: Samples assessed from VC48a.

Plant macrofossils

1.78–2.40 m: Beaked tasselweed (*Ruppia*) fruits were present here, pointing to brackish water conditions, consistent with the evidence from ostracods and foraminiferans in this core (see below), though there was also a small freshwater aquatic component (pondweeds) and a small terrestrial component (oak bud-scales and fruitstones of dogwood) indicating inwash from further afield, along with stiff rhizome fragments suggesting a reedswamp.

1.24–1.78 m: The very well preserved tasselweed fruits from this level were presumably not far-travelled and indicate brackish water again, with freshwater taxa (including the rather silt-coated pondweed fruits) perhaps inwashed from further upstream.

0.66–1.20 m: Tasselweed was absent from the sample at this level, though pondweed fruits indicate continued influx of freshwater material (contra the marine shell recorded).

0.22–0.62 m: The tasselweed at this level again indicates brackish conditions though the other aquatic plants are certainly consistent with freshwater habitats and perhaps suggest the latter have been washed into a tidal zone where the tasselweed was living.

Ostracoda and Foraminifera assessment

Of the thirty six samples examined, five were barren barren (2.24, 2.30, 2.44, 2.80 and 3.28 m). The remaining samples indicate brackish water conditions throughout, but with greater marine influence apparent in places.

Radiocarbon dates

Three radiocarbon dates were obtained from VC 50. These consisted of a sub-fossil wood fragment from the dark brown peaty silt (2.34 m) which produced a date of 7930 ± 50 BP (Beta-260807, Cal BC 7040 to 6650 (Cal BP 8990 to 8600)), and *Corylus* nuts (2.44 m and 2.48 m) which produced dates of 8180 ± 50 BP (Beta-260808, Cal BC 7340 to 7060) and 8230 ± 50 BP (Beta-260809, Cal BC 7460-7470) respectively. The Bayesian model of this sequence of radiocarbon dates is presented in Figure 5.6.10 and Table 5.6.32.

VC 51 and 51a

Coring group:	4 (see Fig. 1 Figure 5.6.1)
Total recovery:	2.63 m
Northing:	369400.58
Easting:	5907192.49
Water depth:	24.01 m

Stratigraphy and subsampling summary (51 and 51a)

Pollen Analysis

VC 51

This sequence was selected for further analysis with 14 samples taken at 0.08 m intervals between 0.16 and 1.24 m throughout the grey silt with humified organics layer. The results of the pollen analysis of VC 51 are presented as a pollen diagram (Figure 5.6.11). The 3 basal samples (1.08, 1.16 and 1.24 m) were omitted from the pollen diagram due to low counts or absent pollen

Depth/m	Troels Smith	Description
0.0–0.14	Ga2 Gg(min)1 ptm1	coarse sand with small stones
0.14–30	Sh2 Ag2	organic rich silt, very sharp boundary
0.30–0.36	Sh3 Ag1	Well humified silty peat. very sharp boundary
0.36–0.83	Ag2 Sh1 As1 Gg(min)+	Clayey-silt with organic, decreasing to base
0.83–1.00	As3Ag1	Stiff grey brown clay with occasional chalk gravel
3.82–4.07	Gmin2 Gmaj1	Soft buff sand, weakly laminated, wood @ 3.94, darker at base

Table 5.6.27: Sedimentary description of VC49.

Core	Depth	Sediment	Pollen	Ostracods	Bulks	Dates
VC49	0.14 m	well humified organic dark brown silty sediment				
	0.31 m					

Table 5.6.28: Samples assessed from VC49.

grains. Pollen concentrations were generally excellent throughout. Preservation was recorded as excellent in the upper 5 samples and declined in the lower section of the diagram where it was recorded medium (3) in sample 0.88 and 1.00 m.

VC 51a

This sequence was selected for further analyses with 18 samples taken at 0.04 m intervals (where stratigraphy allowed) between 0.10 and 0.86 m throughout the black grey organic silt layer. The results of the pollen analysis of VC 51a are presented as a pollen diagram (Figure 5.6.12 and Table 5.6.34) which has been divided into two local pollen assemblage zones with the site prefix 'VC 51a'. Pollen was absent or present in very low concentrations in the basal samples (0.86 m, 0.82 m, 0.78 m and 0.74 m), which have therefore been omitted from the pollen diagram along with sample 0.30 m which produced a low count. Concentrations and preservation varies throughout the entire diagram from good (4) to very low (1). Preservation tends to be higher in the upper section of the diagram (0.10–0.50 m) and corroded and degraded grains were noted below this.

Ostracoda and foraminifera assessment

Five samples were assessed (0.16, 0.48, 0.80, 1.12 and 1.44 m) but only the uppermost two samples (0.16 and 0.48 m) contained microfossils. The relatively low diversity but high abundance suggests somewhat 'stressed' conditions, possibly due to salinity fluctuation. The abundant occurrence of *C. fuscata* suggests that these fluctuations were occurring towards the freshwater end of an estuarine systems and that mean salinity was relatively low-brackish.

Plant macrofossils (VC 51a)

0.47–0.95 m: Woodland material was present here in the form of bark, with perhaps some bast, as well as fruitstones of wild plum/bullace, and woodland mosses, though the 'stiff' rhizome fragments probably indicate inwash of these into a reedswamp (where other

Depth/m	Troels Smith	Description
0–0.20	Ga2 Gg(min)1 ptm1	Coarse shelly sands
0.20–0.50	Ag3 Gmin1 Ptm+	Grey silt with coarse sands, shell fragments
0.50–1.75	Ag2 As2 Sh+	Grey clayey silt, slightly organic
1.75–2.04	Ag3 Gmin1 Ptm+	Grey blue weakly laminated silts with shells and shelly fragments
2.04–2.34	Ag2 Ptm2	Grey blue weakly laminated silts becoming more shell rich
2.34–2.44	Ag2 Sh2 Dg+	Dark grey brown peaty silt with humified organics
2.44–3.40	As2 Gmin2 Gmaj+ Sh+	Grey sandy clay, rare humified organics and flinty pebbles
3.40–3.90	Gmin2 Gmaj1 Ag1	Grey sandy clay/coarse grey silt, large pebbles black clasts, angular pebbles
3.90–4.40	As3 Ag1	Dense grey-brown clay, chalky pebbles.

Table 5.6.29: Sedimentary description of VC50.

marsh/fen taxa will also have originated, of which reedmacro was the most abundant and perhaps identifies the rhizome fragments).

0.10–0.47 m: The 'stiff' flattened rhizome fragments seen in the sample beneath and from elsewhere in these cores were again present here; the only identified propagules were those of reedmacro which perhaps suggests that this is the source of the rhizomes.

Chronology

Three OSL dates are available for this sequence. The uppermost sample of grey silt produced an estimate of 7.8 ± 0.9 Ka (0.60–0.70 m, GI-09076), with estimates of 80 ± 9 (0.90–1.0 m, GL-09077) and 60 ± 8 (1.07–1.17 m, GL-09078) available from grey silty sand towards the base of the core. The chronological model and associated posterior density estimates are presented in Figure 5.6.13 and Table 5.6.35.

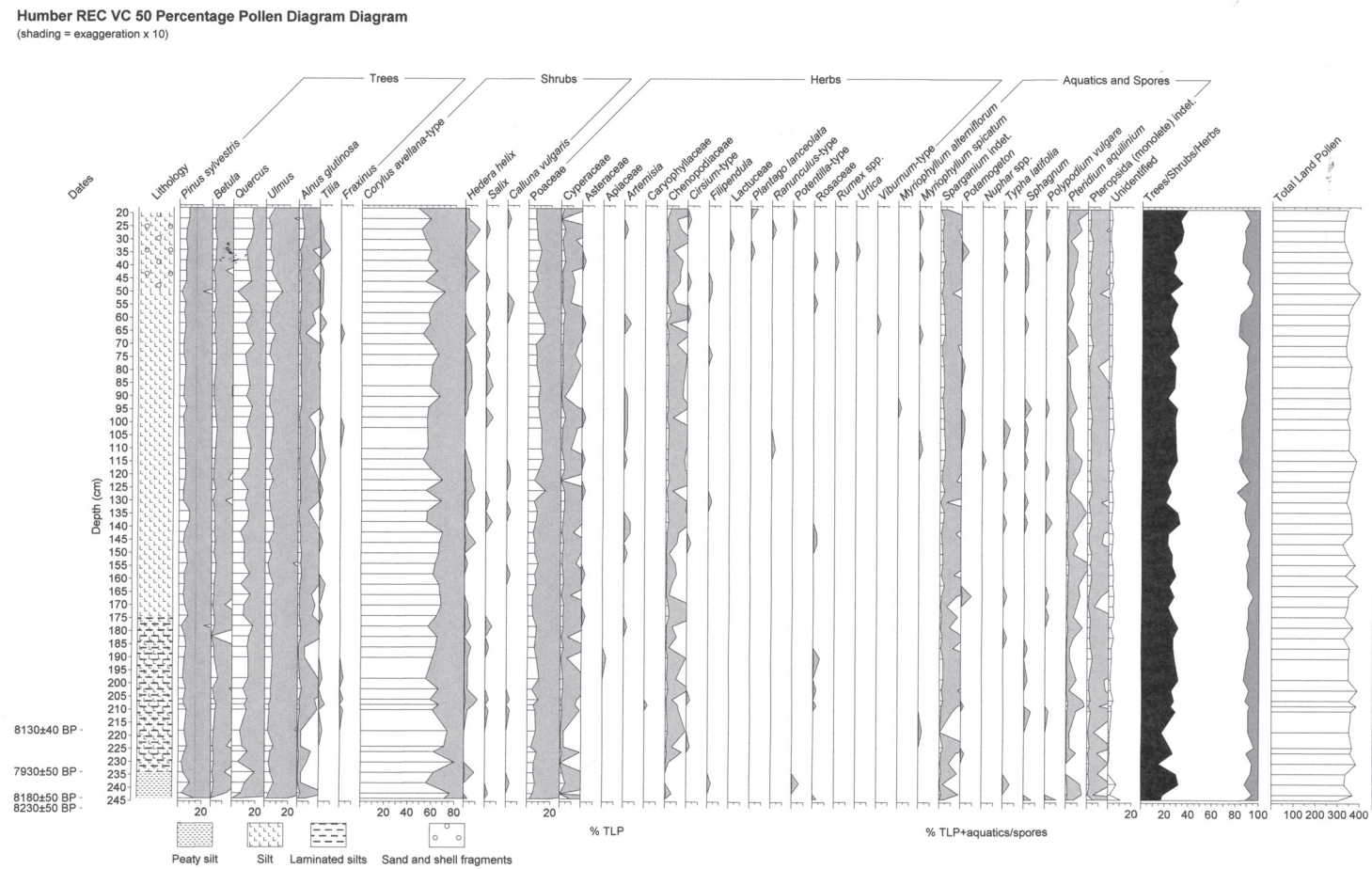


Figure 5.6.9: VC 50 pollen diagram.

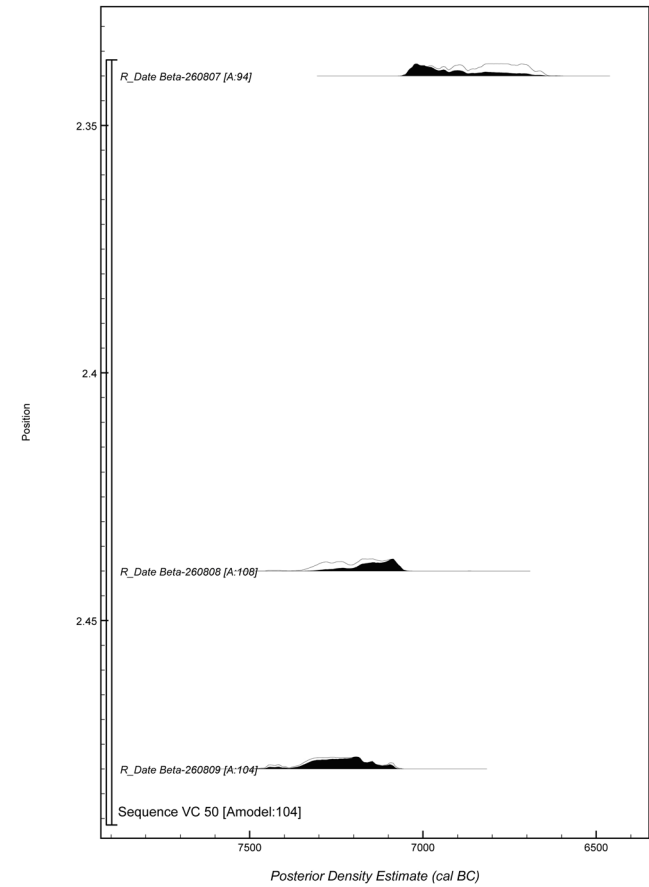


Figure 5.6.10: VC50 chronological model.

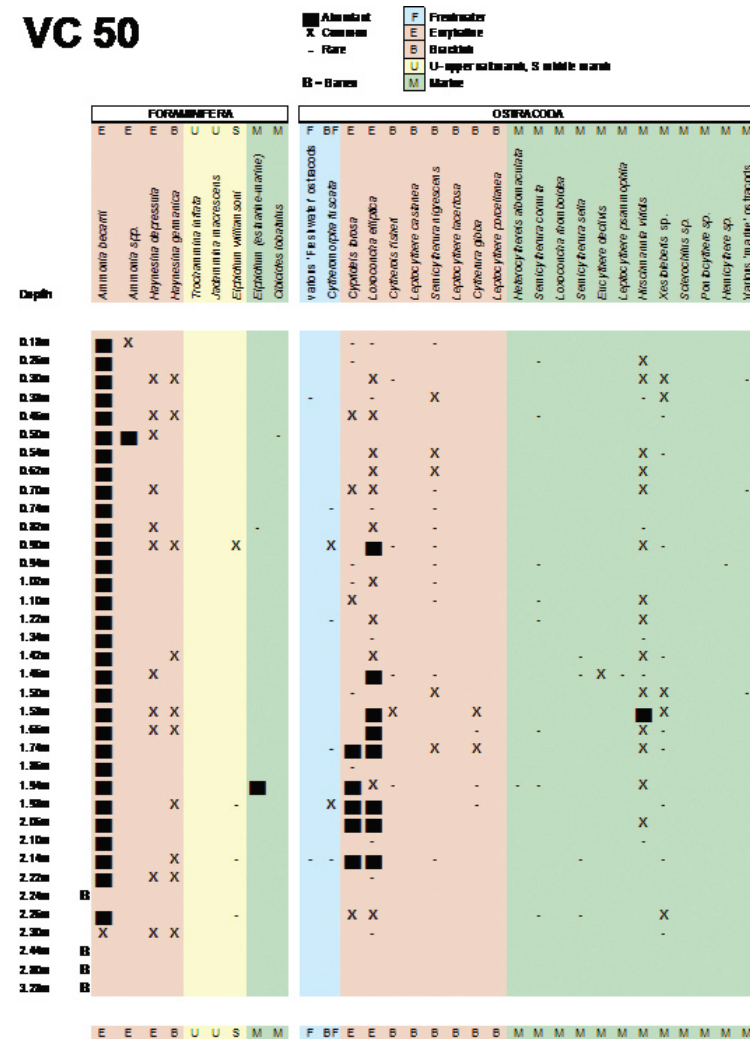


Table 5.6.30: Ostracod and foraminifera analysis from VC 50.

Date-code	68% probability	95% probability
Beta-260809	7330-7140 cal BC	7450-7080 cal BC
Beta-260808	7180-7070 cal BC	7290-7050 cal BC
Beta-260807	7050-6800 cal BC	7050-6700 cal BC

Table 5.6.31: Posterior density estimates for VC50 (radiocarbon dates).

5.6.4 Interpretation and Discussion

The following interpretation and discussion will consider coring groups 4, 6 and 8, upon which the detailed palaeoenvironmental analyses have focussed. The results of the coring and stratigraphic

recording of groups 1–3 and 5 will be then be discussed prior to an overall consideration of the results of this part of the project. The dates in italics in the text below are posterior density estimates derived from the chronological models presented in the previous section (see above Section 2.6).

Group 4 (VC 16, 17, 18, 48, 49, 50 and 51)

Eight cores were sampled from group 4: VC 49 was recovered from c. 100 m south and VC 19 from 600 m south of the geophysics line (Figure 5.3.14); the stratigraphy of both these cores suggests they are associated with the extension of the channel system outside the line of the geophysical survey. This group represents the most spatially intensively investigated location in the REC study area. The sequence of cores effectively sample three discrete features interpreted from the geophysics as at least two infilled palaeochannels. For the sake of discussion, the cores in this group will be further sub-divided into three clusters: group 4a (VC 16, 17 and 48 and 48a), group 4b (VC 18 and 50) and group 4c (VC 51 and 51a). Each of these sub-groups effectively samples a separate part of the system.

Group 4a (VC 16, 17 and 48)

This is the feature at the south-western end of the survey line, with the three cores sampling what appear to be the shallower edges of an incised channel (Figure 5.6.14). Analyses and dating concentrated on VC 48 as this recovered the thickest unit of organic deposits. VC 17 recovered a greater total depth (2.17 m) but the basal 1.15 m of this was interpreted as boulder clay. The stratigraphies of VC 16 and 48 are broadly similar, consisting of marine sands overlying grey sandy, organic silts above peaty silt. This organic unit is underlain by silts and clays in both cores with dense basal clay sediment interpreted as boulder clay. The peaty silt is not recorded in VC 17, where thin grey silt with organic remains directly overlies silty, pebble rich clay. Directly correlating the stratigraphy of these cores is problematic, but the absence of peaty silt from VC 17 may reflect the location of this core close to the edge of the interpreted channel.

No OSL dates are available for this sub-group, but two radiocarbon dates from the basal organic sediments of VC 16 and 48 of 8420 ± 50 BP (Beta-277314) and 8060±50 BP (Beta-260806) respectively, demonstrate that this section of the palaeochannel

began to aggrade in the early Holocene. It should be observed that the cores do not sample what the geophysical data indicates is the deepest part of the channel, hence earlier sediments associated with channel in-fill may be present at this location. The plant macrofossil and beetle samples from VC 48a demonstrate the presence of aquatic environments during the early stages of sediment accumulation, with a rich aquatic flora including *Glyceria*, *Typha*, *Carex* and *Phragmites*, pollen record from VC 48 is dominated by tree and shrub taxa, with *Corylus*, *Quercus* and *Pinus* well represented, implying the presence of mature woodland in the pollen catchment. Few aquatic taxa are recorded, other than relatively high percentages of *Sparganium*, which confirms the impression that deposition was taking place in a shallow, probably freshwater environment.

Depth/m	Troels Smith	Description
0–0.15	Ga2Gg(min)2	Shelly sands
0.15–1.30	Ag4 Dg+	Grey silt with humified organics, coarser below 1 m, sands and fine gravels
1.30–1.50	Ag2 Gmin2 Sh+ Dg+	Grey sandy silt with occ. humified organics
1.50–2.63	As3 Ag1	Dense grey brown clay with chalky pebbles
0–0.10	Poor recovery	Mixed and loose, was possibly shelly sand
0.10–0.95	Dh1 Ag3 As1 ptm++ Gmin++	Black grey organic silt, bands of shelly sand 0.24–0.27 m, 0.38–0.42 m
0.95–1.20	Ag2 Gmin2	Light grey silt sand
1.20–2.36	Ag2 As2	Light brown silt clay occ charcoal, occ chalk

Table 5.6.32: Sedimentary description of VC51 and 51a.

The overlying silts in VC 48 contain further evidence for initially freshwater environments, with *Chara* (stone wort oogonia) and *Zanichellia palustris* (horned pondweed) in the plant macrofossil record and ostracods/forams and diatoms typical of freshwater and low brackish conditions. The ostracod/foram analyses of VC 48 suggest that the influence of freshwater appears to weaken towards the top of the silt deposits, with marine shells as well as *Phragmites* rhizomes apparent in the macrofossil samples from this

sequence, prior to the establishment of full marine conditions as indicated by the overlying coarse sands. The pollen record appears somewhat complacent to these landscape changes; possibly a reflection of the relatively large pollen catchment of channel sediments, rather than the persistence of woodland around the sampling site (see below). The lack of OSL dates prevents the establishment of an absolute chronology for these events.

Core/Code	Posterior Density Estimate 95% probability	Water Depth (m OD)
51a:GL09076	9580–5970 cal. BP	-24.01 m
39a: GL09067	9840–7830 cal. BP	-31.68 m
29b: GL09061	6610–5180 cal. BP	-23.9 m

Table 5.6.33: Posterior density estimates (95% cal. BP) for the uppermost OSL dates for VC29b, 39a and 51a. These can be regared as *termini post quem* for full marine inundation (see text) at each location.

Group 4b (VC 18 and 50)

This group sampled a feature in the central section of the survey line, which was interpreted as a subsidiary palaeochannel of the larger channel to the north-east (group 6c). The total recovered depths (c. 3m) and associated stratigraphies of both cores are broadly similar, consisting of marine sands overlying grey, slightly organic silts sealing peaty silt above silts and stiff brown clay at the base. However, between 1.75-2.34m a distinct unit of weakly laminated silty sands with marine shells is recorded in VC 50 overlying the peaty silt. No plant macrofossil, beetle or OSL dates are available from these cores. As with the other pollen diagrams discussed above, the pollen data from VC 50 show remarkably few changes associated with the effects of rising RSL or other landscape scale processes.

The base of the peaty silt deposits in VC 50 are dated to 8230 ± 50 BP (Beta-260809; 7460-7070 cal. BC, 2.48 m) with another date of 8180 + 50 BP (Beta-260808, 7350–7050 cal. BC, 2.44 m) corresponding to the middle of the organic layer. As with group 4a, this indicates that this channel also began to aggrade during the early Holocene, with the deposition of silty organic reflecting

Humber VC51 Percentage Pollen Diagram
(Shading = exaggeration x 10)

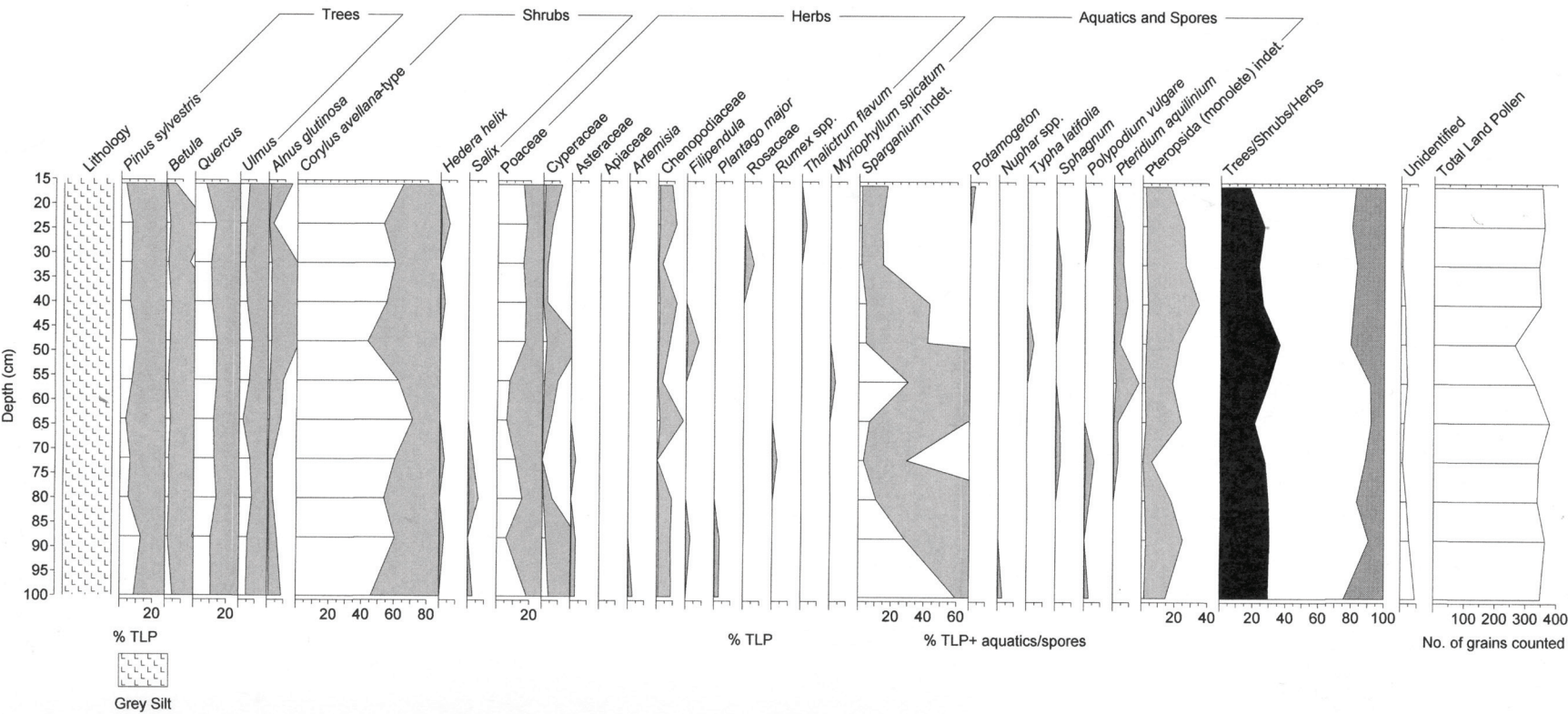


Figure 5.6.11: VC51 pollen diagram.

the paludification of the channel base in response to rising RSL. Bayesian modelling of these dates suggests that the period of organic accumulation took place between 7450–7080 cal. BC (Beta 260809) and 7050–6700 cal. BC (Beta-260807) after which there is a stratigraphic shift from the peaty silts to weakly laminated shell rich silts (1.75–2.34 m).

The stratigraphy of this latter unit suggests the re-activation of the channel, with the presence of marine shells possibly reflecting the deposition of material flushed upstream from further down the drainage network. The ostracod/foram sample from 1.94 m may confirm this interpretation, containing fauna indicative of marine environments. An event such as a tidal surge might have been responsible for this, but the precise timing and nature of processes of change at this time are unclear on the basis of the current data. A further radiocarbon date of 8130 + 40 BP (Beta-280040,

7180–7050 cal. BC) from a fragment of wood from this unit is too old compared to the underlying dates, suggesting it represents a fragment of older material, re-worked by the processes which deposited the shell-rich sands. The subsequent accumulation of the silts in both VC 50 and VC 18 was in a brackish water environment, suggesting that the influence of full marine conditions was not sustained. The presence of coarse sands and shells towards the top of VC 50 indicates the encroachment of marine conditions at the sampling site but no OSL or radiocarbon dates are available for this transition.

Group 4c (VC 51 and 51a)

This third group includes one core which samples the edge of a large possible palaeochannel feature. Two duplicate cores were taken and pollen, macrofossil and ostracod analyses were carried out on these sequences with three OSL dates available. Two of

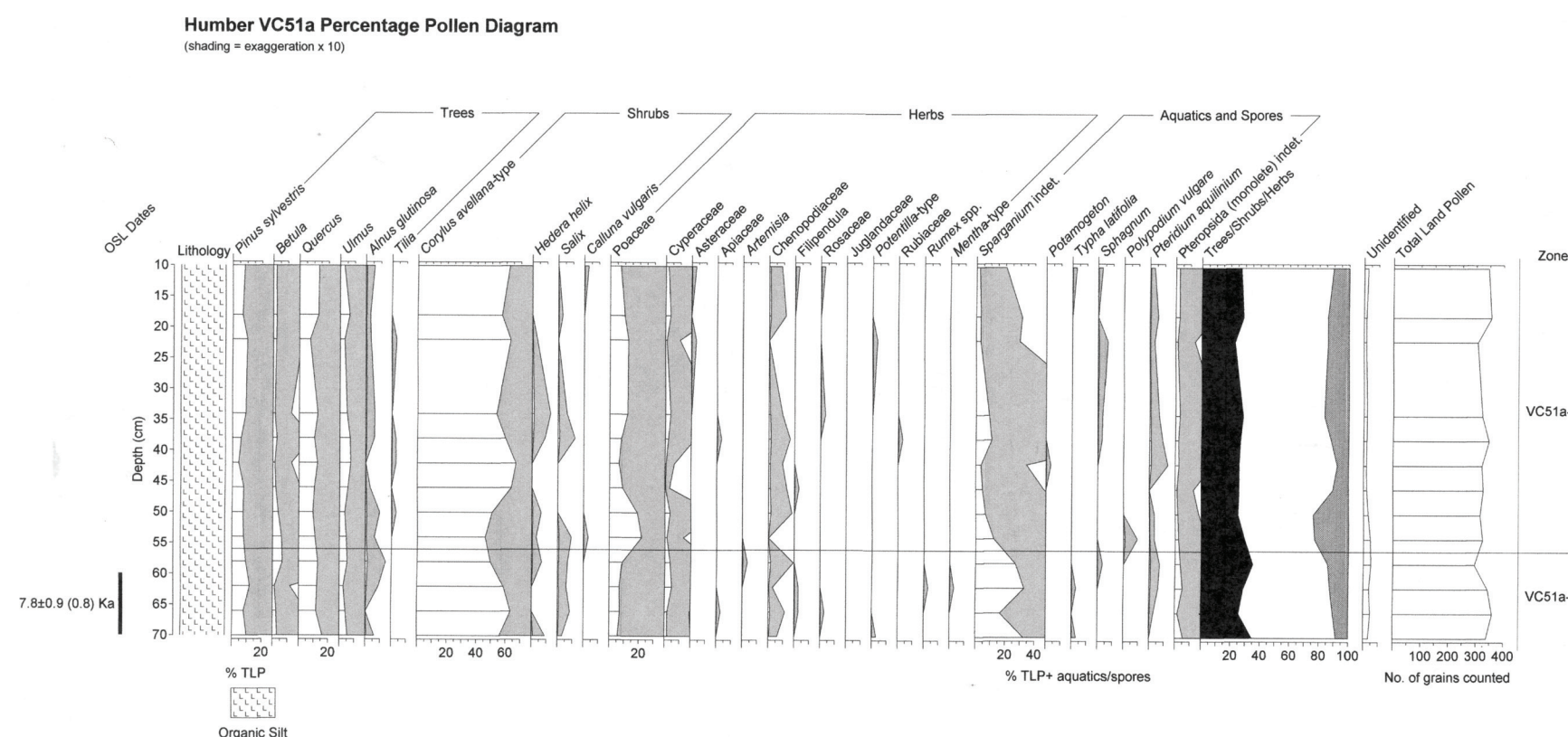


Figure 5.6.12: VC51a pollen diagram.

these OSL dates demonstrate that the deepest silty-sand deposits in VC 51 were accumulating during the Upper Pleistocene between estimated dates of 93 120–59 390 BC (GL-09078, 1.07–1.17 m) and 71 900–42 100 BC (GL-09077, 0.90–1.0 m). These silty-sands appear to reflect glaciofluvial processes although it is unclear if they represent the fill of an earlier channel or if the channel was incised into these deposits at a later date. Deeply incised sub-glacial valleys in the southern North Sea area have been interpreted as being formed by ice scouring and/or meltwater discharge during the main ice advances of the Devensian (e.g. Cameron *et al.* 1987).

There is clearly a significant hiatus in deposition, as the OSL date from 0.60–0.70 m indicates that the accumulation of the organic silt overlying these Upper Pleistocene sands commenced during the early Holocene at an estimated date of 7630–4020 cal. BC (GL-09076). The plant macrofossil record from this unit contains a range of evidence of both woodland environments as well as aquatic habitats, which may again suggest that organic material

was being washed from terrestrial sources into the channel, where reedswamp communities with *Typha* and *Phragmites* vegetation were growing. The ostracod and forams imply that the deposition of the silts was taking place at the freshwater end of an estuarine system, with low/brackish salinity.

The pollen diagram is dominated by trees and shrubs including *Corylus*, *Quercus*, *Ulmus* and *Pinus*. The spectra show little significant change, other than *Sparganium* which is relatively abundant at the base of the sequence but declines towards the top of the diagram, suggesting that bur-reed populations decreased as the channel infilled. The transition to full marine conditions is not apparent in any of the palaeoenvironmental analyses. Although the stratigraphic transition at a depth of 0.10 m in VC 51a demonstrates this process, no OSL dates are available from this part of the core.

The palaeoenvironmental analyses and associated OSL/radiocarbon dating programme thus confirm the interpretation of

the geophysical data as indicating a series of palaeochannels, with the profile reflecting a section through an anastomosing/braided river system. The OSL dates from VC 51a demonstrate that the deepest sediments recovered in this core were deposited during the Upper Pleistocene. Whilst the date range for channel incision remains to be firmly established, it can be hypothesised that the channels had begun to aggrade by the 8th millennium BC with the accumulation of the possible detrital peat/organic sediment. The impression is of mature deciduous woodland in the close vicinity of the sampling sites at this time, although the interpretation of the proxy data, the pollen record in particular, is affected by a number of taphonomic factors (see below).

It is clear that initial sediment accumulation at this sampling site was in a freshwater environment, with a range of plants including

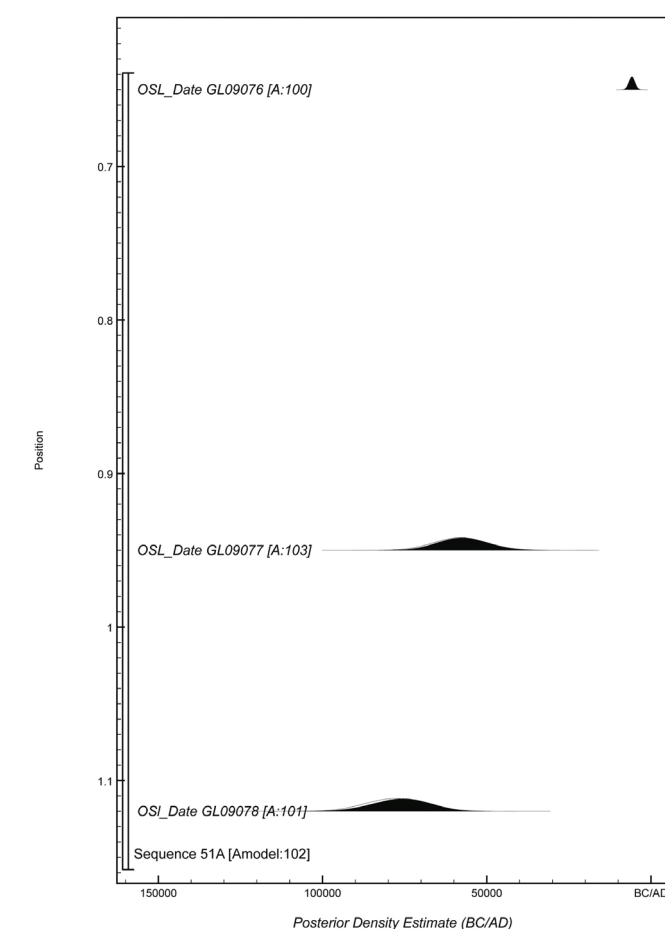


Figure 5.6.13: VC51a chronological model.

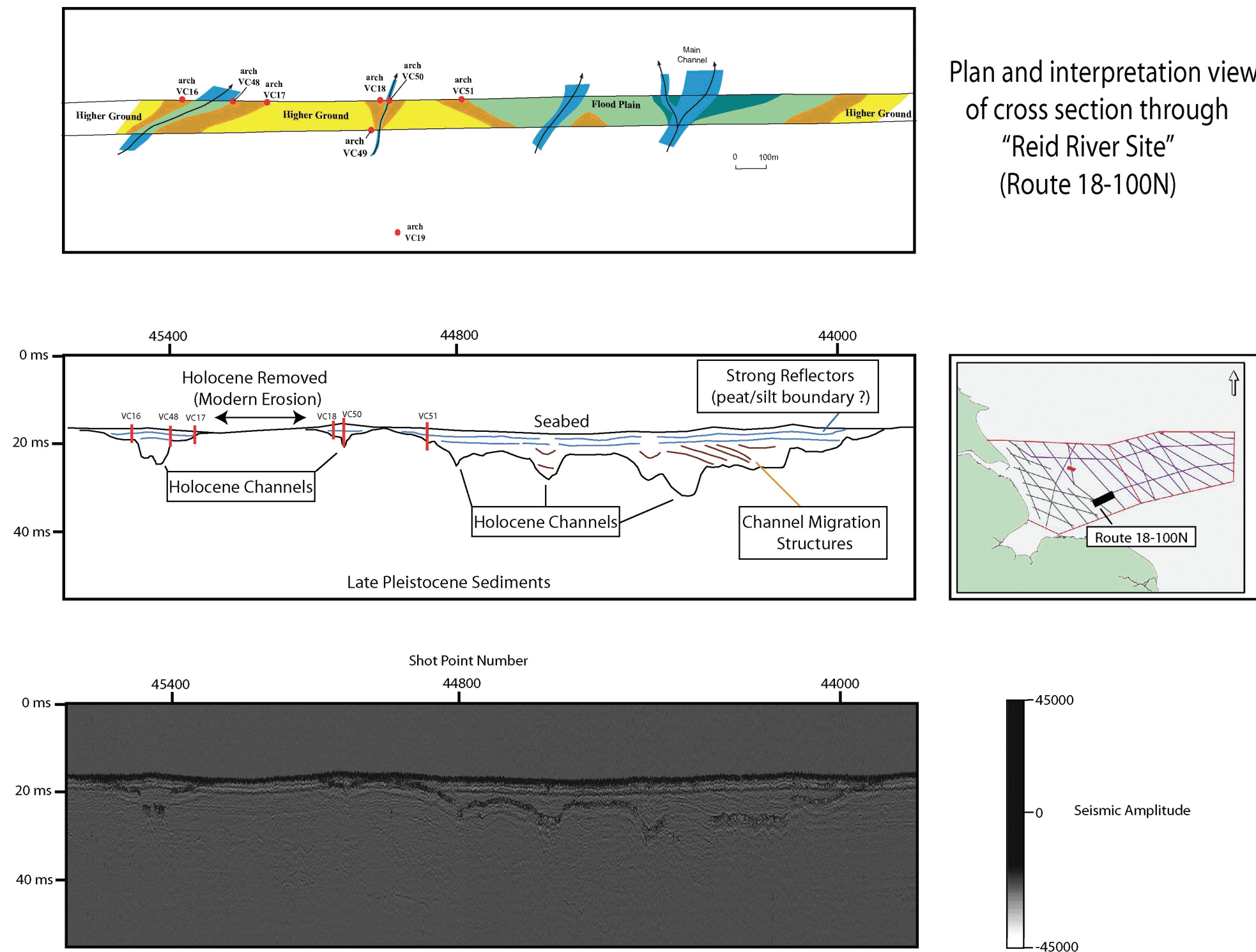


Figure 5.6.14: Coring group 4: 3D (top) and 2D (bottom) geophysics with interpretation (centre) and survey location (centre right).

Typha (reedmace), *Phragmites* (reeds) and *Carex* growing in the slowly moving waters during continued channel aggradation. The ostracod and foram analyses support this interpretation with indications of brackish and freshwater conditions throughout the analysed cores in this group but with some limited evidence for this influence weakening towards the top of the silt deposits. There is no clear indication in these data for the advent of full marine conditions in any of the analysed sequences. The lack of OSL dates from the shallower deposits in the cores from this group prevents the establishment of a robust chronology for these events or an assessment of the extent to which the records may have been truncated by subsequent marine processes.

Coring group 6 (VC 27-29)

This group of three cores was situated some 40 km to the east of group 4 from a feature identified as a possible palaeochannel (Figure 5.6.15). The palaeoenvironmental and associated dating programme focussed on VC 29 with pollen, plant macrofossil, beetle, ostracod/ foram analyses and OSL and radiocarbon dates available from this sequence. This location hence provides the most comprehensive suite of data available for a single core from this project.

The earliest dated sediments in VC 29b were deposited during the Late Devensian, with OSL dates (Table 5.6.18) providing estimates of 27 760–20 300 cal. BC (GL-09066, 1.98–2.04) and 24 050–16 900 cal. BC (GL-09065, 1.84–1.90 m) available for the base and top of the fine silty sand (1.76–2.04 m) recorded towards the base of this core. These deposits were relatively fine and well sorted and appear to be of glaciofluvial or lacustrine, rather than of glacial origin. There again appears to be a temporal hiatus between these Upper Pleistocene deposits and the overlying organic silts (1.31–1.76 m), which are dated to 13 280–8 500 cal. BC (GL-09064, 1.52–1.58 m) and hence the latter accumulated during the Late-glacial/early Holocene. The basal pollen zone of VC 29 conforms to this deposit and although this core does not have associated OSL dates, the pollen spectra are dominated by *Pinus* and *Corylus*, with some *Ulmus* suggesting an early Holocene landscape with pine, hazel and elm woodland.

The precise character of landscape processes at this time are unclear on the basis of the current data, but it seems probable that the sampled palaeochannel was incised either during the Upper

Pleistocene, prior to 27 760–20 300 cal. BC (GL-09066, 1.98–2.04), or in the period between 24 050–16 900 cal. BC (GL-09065, 1.84–1.90 m) and 13 280–8 500 cal. BC (GL-09064, 1.52–1.58 m) hence possibly during the earlier Holocene. This interpretation hinges on whether the basal sands represent deposition within a channel feature, or alternatively if the channel was incised into this earlier suite of sediments. There is no clear stratigraphic evidence of such an erosive contact between the organic silts and basal sands, which may support the former hypothesis, but the absence of associated stratigraphic data prevents a conclusive interpretation.

The organic silt is interpreted as reflecting the beginning of channel aggradation as RSL began to rise, causing a shift from a net erosional to depositional regime at the sampling site. Such processes led to the formation of the silty peat as the channel base paludified, at an estimated date of 7 300–6 820 cal. BC (Beta-260805, 1.40 m). However, whilst the plant macrofossil record (VC 29a and 29b) appears to confirm the associated pollen data from both VC 29 and 29b in suggesting the existence of mature *Quercus* woodland in the landscape at this time, whilst the beetle samples from VC 29a also contained species indicative of deciduous woodland as well as evidence for aquatic environments.

There is other evidence in the form of the highly minerogenic nature of the sediment and the presence of *Cenococcum sclerotia* (fungal resting bodies) in VC 48 that the organic unit represents in part at least, re-worked material from dryland soils rather than *in situ* peat formation. The presence of charcoal in the basal sample from VC 48 may imply that this disturbance was associated with the burning of vegetation, although the causes of this are unknown. The deposition of eroded sediment from further upstream may have resulted from the ‘backing up’ of the drainage system perhaps associated with rising RSL. The good preservation of the beetle fauna would seem to be slightly at odds with the possible evidence that the organics did not accumulate *in situ*, as a more fragmented assemblage might be anticipated had the material been transported any distance. It is possible that the deposit incorporates both *in situ* and re-deposited sediment.

Either way, this period of peat formation/organic accumulation was evidently relatively short lived, with the transition to increasingly minerogenic silts recorded from an estimated date of 7070–4630

cal. BC (GL-09063, 1.20–1.28 m). The macrofossil record again includes evidence for further possible re-working and re-deposition from terrestrial sources, although the presence of *Phragmites* rhizomes implies the growth of reedswamp in the channel. The pollen record suggests the persistence of *Quercus*, *Corylus* and *Pinus* dominated woodland in the wider landscape although the interpretation of these data in terms of site specific vegetation are again in some ways problematic (see below). Few herbs are recorded aside from Poaceae, which may reflect the presence of the wetland grasses *Phragmites* apparent in the macrofossil record, rather than open environments on the drier soils, of which there is little other evidence in any of the pollen diagrams.

The forams/ostracods from VC 29 demonstrate that the deposition of the silts was within a brackish water environment with evidence for proximity to intertidal saltmarsh environments. The record of Chenopodiaceae in the pollen record may indicate the presence of taxa associated with such habitats, after an estimated date of 4940–3620 cal. BC (GL-09062, 0.89–0.99 m). The macrofossil sample from VC 29a contained stinking goosefoot (*Chenopodium vulvaria*) a plant that grows in brackish places near the sea and it is hence probable that the pollen data also reflects, in part at least, the presence of this species. There is also evidence in both the macrofossil and pollen records for *Quercus* woodland, although it is unclear if such woodland was proximal to the channel or if the proxy evidence was being washed into the sampling site from terrestrial environments somewhat upstream. The transition to shell rich silty sand at a depth of 0.72 m marks the termination of the pollen record in VC 29b, around an estimated date of 4660–3230 cal. BC (GL-09061, 0.59–0.69 m). The accumulation of increasingly shell rich coarse sands after this point reflects the subsequent establishment of full marine conditions on the sampling site.

In summary, this sequence suggests a channel that was incised during the Upper Pleistocene or alternatively the Late-glacial/earliest Holocene, when sea levels were rising from perhaps some 130 m below OD (e.g. Streif 2004). Rising sea levels in the early Holocene resulted in channel aggradation, initially under fresh water conditions. At this time, the area around the channel was presumably dryland and there is possible evidence for the presence of deciduous woodland close to the sampling site. A brief

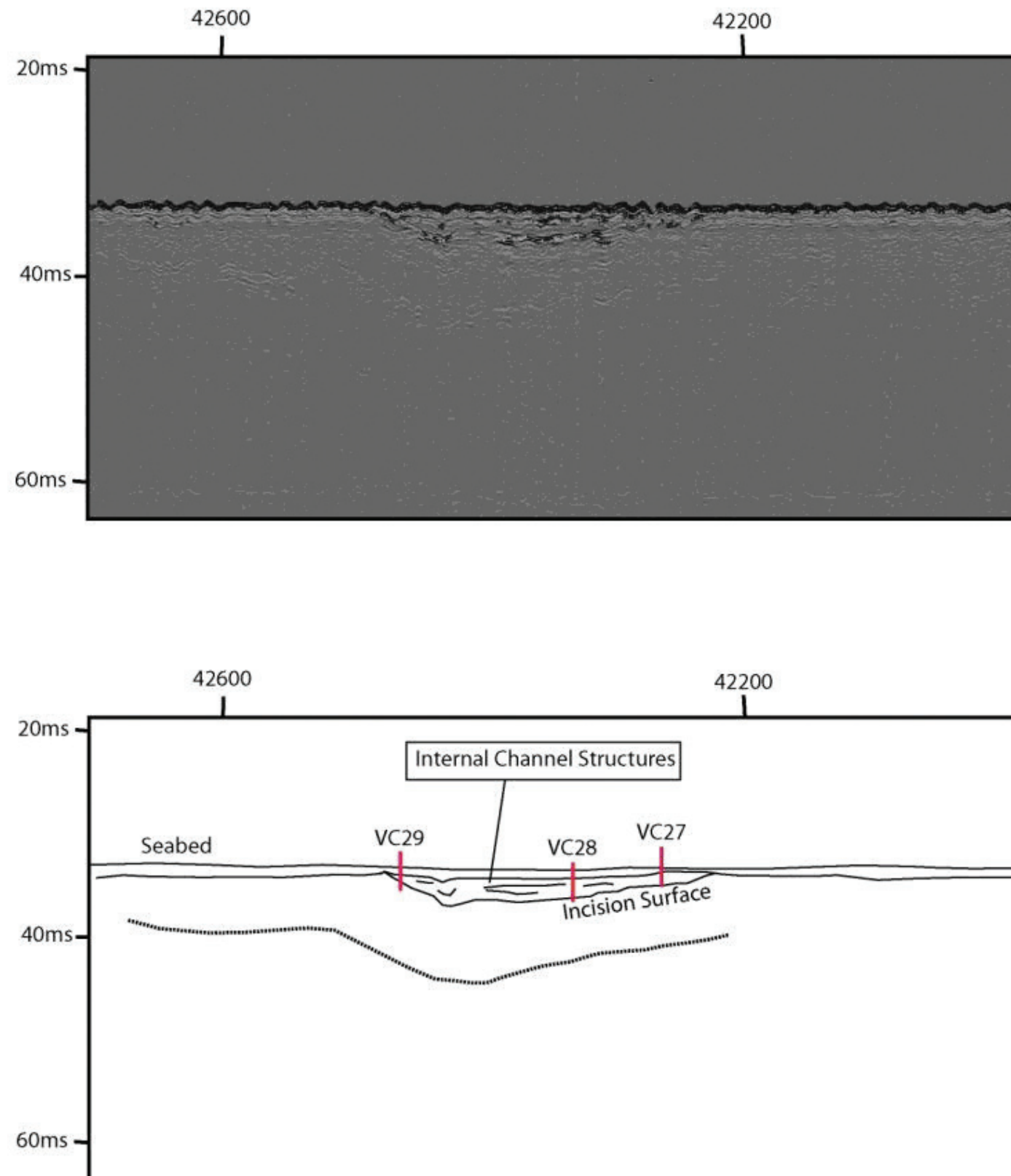


Figure 5.6.15: Coring group 6 geophysics and interpretation.

period of peat accumulation or perhaps the re-deposition of organic material from elsewhere in the catchment during the late 8th/early 7th millennium BC was followed by the accumulation of minerogenic silts in the channel in an estuarine environment, prior to inundation and establishment of full marine conditions at sometime after the late 5th/early 4th millennium BC. The associated core at this location, VC 27 consisted of less than a metre of coarse sands and silts onto boulder clay. Whilst these sediments are possibly also indicative of a palaeochannel fill, it is difficult to relate these to VC 29 without further stratigraphic data.

Group 8 (VC 39, 39a and 40)

This coring group is most easterly of those locations investigated and was sited to investigate a possible palaeochannel feature (Figure 5.6.16). OSL dating and foram/ostracod analyses only were carried out on VC 48a as the predominantly minerogenic nature of these sediments did not suggest that any other palaeoenvironmental analyses would be worthwhile. The modelling of the OSL dates (Table 5.6.21) indicate that the basal sandy clays at this location began accumulating in the earlier Holocene at an estimated date of 8230–6580 cal. BC (GL-09070, 2.16–2.26 m), with the subsequent series of dates implying that accumulation may have been fairly rapid. A transition from laminated sands/silts to the upper shell rich sands at 1.36 m presumably demonstrates the establishment of full marine conditions at the sampling site. A terminus ante quem for this is available from the estimated date of 7920–6280 cal. BC (GL-09068, 1.02–1.10 m), with that of 7890–5880 cal. BC (GL-09067, 0.45–0.55 m) the uppermost date for the shell rich sands.

The ostracod/foram samples (1.16 m, 1.32 and 1.64 m) suggested euryhaline-brackish salinities with an influence of both upper and lower saltmarsh, with a number of rare occurrences of open marine ostracods in the bottom sample (1.64 m). This probably reflects re-deposition at the sampling location during a phase of increased marine influence. The stratigraphy of this core indicates somewhat different depositional environments compared to groups 4 and 6, with the dominance of coarser sands and lack of silts and organic material demonstrating a higher energy fluvial environment more typical of a sub-tidal context.

Coring group 1 (VC 1 and 2)

This group of two cores (VC 1 and 2) sampled another possible

palaeochannel feature (Figure 5.6.17). The stratigraphy of VC 1 consisted of marine sands and gravelly sands (0.30 m) above a layer of (1.69 m thick) silty clay with rare organics and shell fragments. VC 2 consisted of marine sands with subangular gravels overlying boulder clay at 1.40 m. The silty clay deposit in VC 1 suggests some form of channel fill at this location, but no assessment work was carried out on this core hence the age and precise character of these deposits remain unknown.

Coring group 2 (VC 9, 12 and 46; VC 14, 15 and 47 and 47a)

This group consisted of 6 cores which sampled the south-western and north-eastern sides of a possible sediment trap/palaeochannel (Figure 5.6.18). However, the majority of the cores consisted of relatively shallow depths of marine sands, pebble and silts onto silty clay with shell fragments (maximum recovery 0.75 m in VC 9) and appear to have missed the greatest implied depth of sediment. VC 47 and 47a were more successfully targeted onto the centre of the feature and a depth of over 4 m of intercalated sands and silts was recovered. The OSL dates suggest accumulation of marine sands at this location from the later Holocene (c. last 900 years). The deeper silts and clays are possibly of Upper Pleistocene–Late-glacial age, but given the chronological inaccuracies, little other meaningful comment may be made regarding the significance of these deposits with regard to processes of environmental change.

Coring group 5 (VC 25 and 26)

This group consisted of two cores aimed at establishing the stratigraphy of a feature interpreted as incised into probable Upper Pleistocene sediments (Figure 5.6.19). VC 26 recovered a sequence of medium coarse sands onto dense grey-brown clay (probably boulder clay) at a depth of 2m. VC 25 recovered a greater depth of c. 4.2m of marine shell rich sands with pebbles (0–2.83m) overlying clay-silt (3.83–3.88 m) and medium-fine shell rich sands (3.88–4.21 m). This sequence does suggest the presence of *in situ* deposits, lain down predominantly in a marine environment, but no OSL dates are available and hence the chronology for these sediments remains unknown. No further palaeoenvironmental assessments were carried out on these cores.

Coring group 7 (VC 34 and 35)

This coring group investigated an area mapped as the Yarmouth Roads formation (Cromerian Period) (Figure 5.6.20). VC 34 consisted of coarse shell rich marine sands onto dense grey-brown clays (boulder clay) at a depth of 1.05 m. VC 35 retrieved a greater depth of sediment, with coarse shell rich sands (0–3.66 m) overlying a layer of rounded pebbles (3.66–3.68 m) and grey clay (3.68–4.0 m). This latter sequence suggests the accumulation of presumably Holocene marine deposits with the basal pebbles and clays of unclear age or character. No OSL dating or palaeoenvironmental assessments were carried out on these cores.

5.6.5 The Environment of ‘Doggerland’

The palaeoenvironmental analyses provide evidence of the environment both on as well as around the sampling sites during the early Holocene in particular. However, a range of taphonomic processes complicate the interpretation of certain aspects of these data. As discussed above, there is evidence in the macrofossil samples that some of the more organic material in particular, might not reflect *in situ* formation but re-deposited sediment. Whilst this re-working may have been from soils adjacent to the sampling locations, it is also possible that the material may have been transported some distance from where it originally accumulated. If this is the case, then the analyses do not necessarily reflect the environment immediately proximal to the sampling sites. Likewise, the fluvial origin of the deposits suggests that the pollen spectra probably incorporate, in part at least, a signal from regional vegetation. Separating out the local from the extra-local and regional pollen signals is not straightforward. Certain aspects of the implied changes, such as the reduction in Sparganium recorded in the VC 51 pollen diagram, are probably more likely to reflect local events as such taxa are more likely to have been present on the sampling site. These taphonomic issues regarding possible source areas must be considered in the following discussion.

The presence of macrofossils of *Corylus avellana* in the basal silty peats of VC 50 and this species alongside the cupules from *Quercus* in VC 29 indicates that these tree/shrub species may have been growing on or very near to the channel at this time. Likewise, the abundance of *Corylus* in the pollen record implies that this was a

dominant component of the woodland, although the species may be somewhat overrepresented in the pollen record relative to *Quercus*. The presence of the ‘nut weevil’ *Curculio* and *Megatoma undata* in the bulk samples from VC 48a and *Melasis buprestoides* in VC 29 provide further evidence of local wood and woodland environments. The impression is of a relatively diverse mixed woodland environment at this time, in which *Corylus* and *Quercus* appear to have been dominant but with *Ulmus*, *Pinus sylvestris* and *Betula* also present. The latter is attested by the plant macrofossil record in VC 29, but as observed above, *Betula* seeds can be readily dispersed by wind and water. Other taxa including *Salix*, *Fraxinus* and *Hedera* are also present generally at low values; these tend to be poorly represented palynologically and hence their presence may be inferred.

The structure of the vegetation in the wider landscape is unclear, but the pollen record suggests that soil conditions may have been suitable to support mixed woodland. There is no clear evidence for the environment being under ‘stress’ such as from saltwater incursion, nor is there any palynological evidence for the existence of open areas related to human activity. The percentages of Poaceae and Cyperaceae can probably be attributed largely to the ‘on site’ wetland taxa such as *Phragmites* and *Carex* identified in the plant macrofossil samples. A record of the dung beetle *Aphodius* in VC 29 suggests the presence of large herbivores, but again the implications of this for disturbance to the woodland or the degree of landscape ‘openness’ (see Whitehouse and Smith 2010) are unclear.

5.6.6 Fluvial History and Sea Level Change in the REC Study Area

Figures 5.6.21–5.6.23 plot the location of the Humber REC cores against a series of ‘timeslices’ based on current models for early Holocene changes in RSL. The data suggest that during the Late-glacial/early Holocene, low relative sea level resulted in channel incision across the REC area (Figure 5.6.21). The precise duration of this phase of erosion is unclear but the chronological data (VC 16, 48 and 50 and VC 29) suggest that it predated the last quarter of the eighth millennium BC, with the accumulation of peaty silt in coring groups 4 and 6 recorded from this time. The fact that these locations are relatively far apart (40km) would imply that this reflects a regional rather than local pattern of change. Such peat formation may have been at around the level of mean high spring

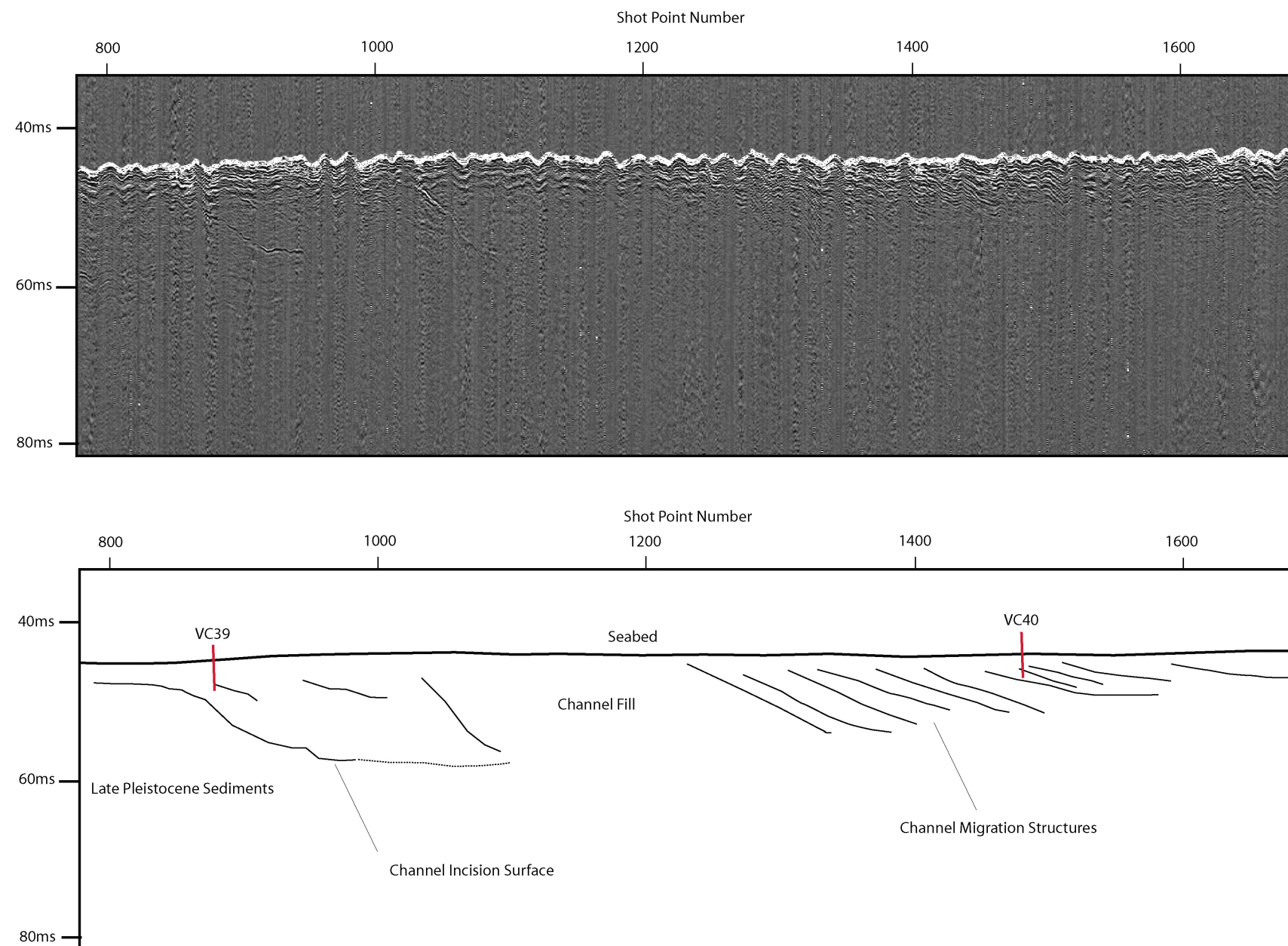


Figure 5.6.16: Coring group 8.

tides or an unknown distance above this; in other words RSL must have been at or below the level at which they are located (Shennan and Horton 2002).

The modelling of the radiocarbon dates from VC 50 indicates that the phase of organic accumulation was relatively shortlived and probably within a few hundred years at most, watertables

had begun to rise. The stratigraphy of the silt deposits and the assessment of plant macrofossil and beetles from these sediments in groups 4 and 6 indicate that the flow regime was probably relatively sluggish, although the presence of coarser sand and shell material immediately above the basal organics in VC 50 (see above) suggests an initial episode of higher energy fluvial conditions. The range of beetles recorded in VC 29a and 48a

includes taxa typical of slow flowing/still water and this phase of deposition may be best interpreted as one during which rising sea level prevented significant drainage in a seawards direction, leading to flooding and backing up of channels, rather than an actual phase of channel re-activation.

The abundance of *Phragmites* alongside related wetland herbaceous taxa *Carex* and *Schoenoplectus* in the macrofossil record (VC 29a and 48a) indicate the presence of extensive reedbeds in or at the margins of the channels and probably relatively shallow water (perhaps a maximum of 2 m deep). The foram/ostracod assessments indicate that these silts were probably deposited under freshwater/brackish conditions, although the deeper samples from VC 50 appear to suggest a greater marine influence. This would seem to imply the deposition of marine fauna perhaps related to a tidal surge, but other than this, little biostratigraphic evidence for full marine conditions is recorded. The sequences on the whole appear to represent increasing relative sea level up core; there is no clear evidence for regressions or phases of sea level stagnancy (cf. Alappat *et al.* 2010).

There is some evidence in the foram/ostracod records for these encroaching marine conditions towards the top of the silt deposits (e.g. VC 29). The taxa identified in the macrofossil samples included rounded-headed club-rush and grass-leaved orache (*Scirpoides holoschoenus* and *Atriplex littoralis*) (1.42–1.85 and 1.85–2.10 m; VC 29a) both of which are found on damp sandy soils near to the coast. These plant macrofossils therefore provide further, relatively scant direct evidence, of marine conditions. It can be noted that there is no clear indication in the pollen records for the impact of rising sea levels on the vegetation. The sequences are dominated by *Corylus* with other trees/shrubs and show remarkably little variation, giving the overall impression of ecological stability rather than flux or change. This may be regarded as evidence that the pollen diagrams are reflecting predominantly regional rather than local vegetation structure. Probably the only evidence for the proximity of saltmarsh habitats are the low but consistent values for *Chenopodiaceae* (fat hen family, includes various salt marsh taxa) recorded in most of the diagrams with occasional records of *Artemisia*-type (wormwood) in some of the pollen records perhaps also suggesting coastal vegetation communities.

The silt units are generally overlain unconformably by the current seabed deposits which may indicate that the final inundation of

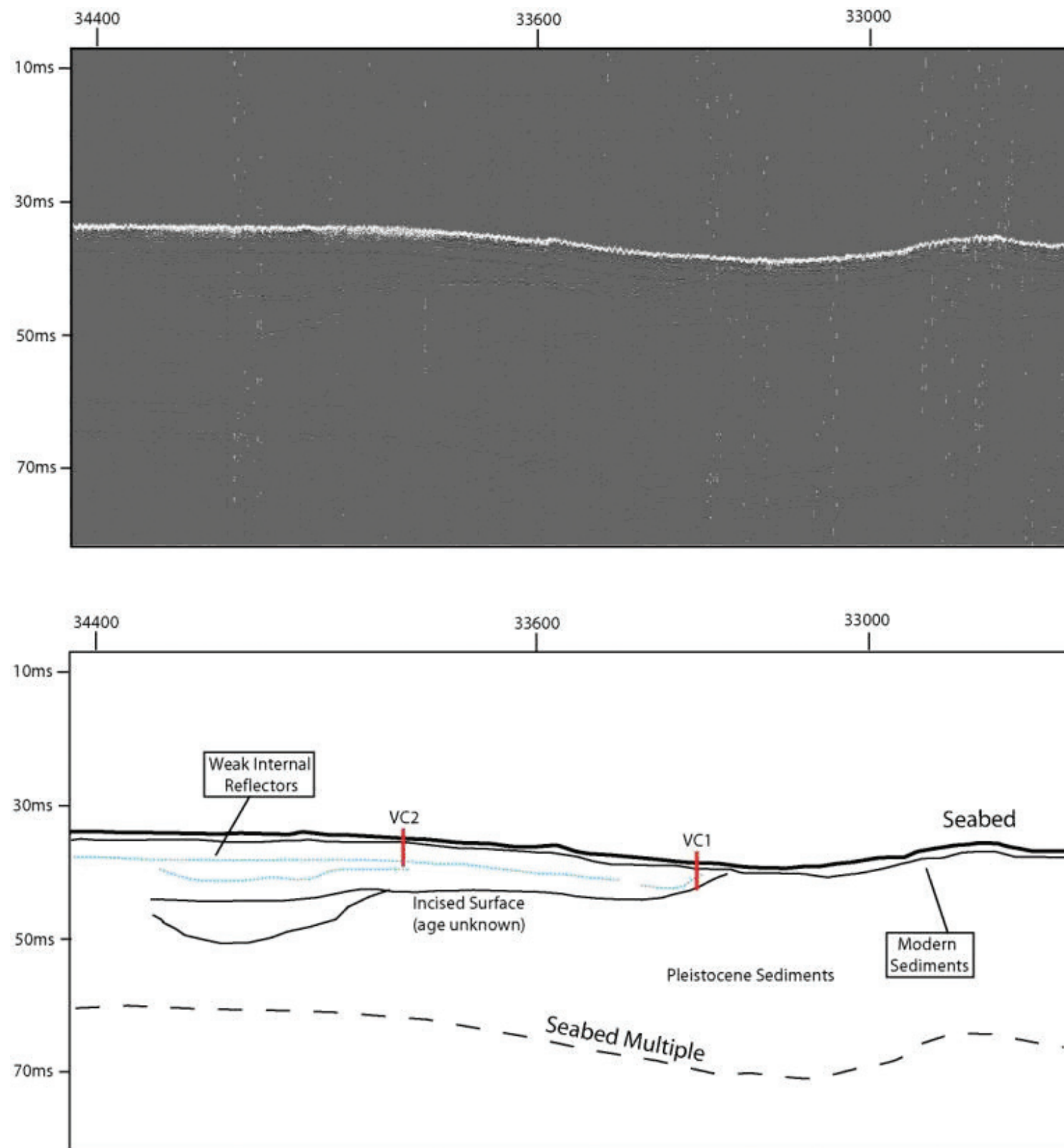


Figure 5.6.17: Coring group 1.

this area was a relatively rapid event. This impression might be reinforced by the fact that the ostracod/foram fauna in the majority of the samples demonstrate little indication of increasing salinity up core, suggesting that brackish water conditions persisted up until a final surge in RSL and the rapid submergence of the area.

Although none of the palaeoenvironmental data can be regarded as having 'indicative meaning' (i.e. a sea level index point with reference to the contemporary tide level), the analysed cores provide information regarding this timing of sea level change in the REC area. The OSL dates from the top of VC 29b, 39a and 51a were obtained on samples which evidently represent sediments laid down in fresh to brackish water, hence providing *termini post quem* for the establishment of full marine conditions at coring groups 6, 8 and 4 respectively (see Table 5.6.36). That of 9840–7830 cal. BP (GL09077) for VC 39a would appear to be broadly in agreement with currently established models of early Holocene RSL for the southern North Sea, indicating that locations further to the east and below -31 m OD were inundated relatively early in the Holocene (Figure 5.6.22). The estimated date of 9680–5970 cal. BP (GL09076) for VC 51a is perhaps slightly later and at a correspondingly higher altitude, but the modelled range, as is the case for all the OSL dates, is relatively broad.

The date of 6610–5180 cal. BP (GL09061) from VC 29b is, given the altitude of this sequence (-24 m OD), an apparently relatively late date for a pre-full marine inundation context (Figure 5.6.23). The significance of this single date in terms of currently established patterns of RSL for the southern North Sea (e.g. Shennan and Horton 2002) is unclear but may suggest that full marine conditions were not established until relatively late at this location. Recently, it has been suggested that the concept of a regionally 'representative' sea level curve has limited value and that small parcels of land (c. 50 km across) may effectively have their own sea level history (see Kiden *et al.* 2002). It is possible that the chronology from VC 29b reflects this, but further work is clearly required to investigate patterns and processes of RSL in this part of the southern North Sea. The current data suggest that it is unlikely that *in situ* deposits survive beyond the protected confines of incised channels, but further work is required to investigate this further. The preservation of archaeological remains within palaeochannels on dry land indicates

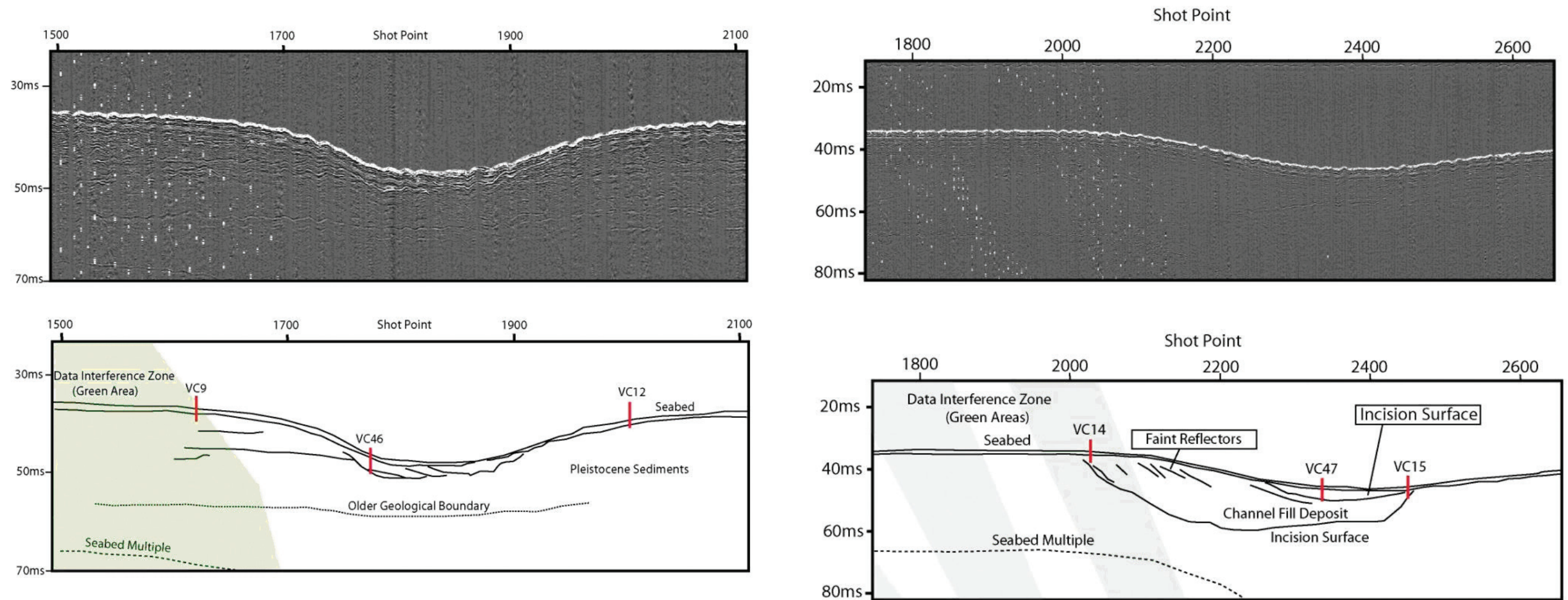


Figure 5.6.18: Coring group 2.

the possibility of such material surviving within similar contexts in the submarine zone. Locating and investigating any such remains would be highly problematic.

5.6.7 Implications for Human Activity and the Archaeological Record

The full interpretation of the above palaeoenvironmental data in terms of the likelihood and subsequent character of past human activity depends in part on understanding of the topography of the pre-inundation landscape. For example, the implications of the possible relatively late (4th–5th millennium BC) marine inundation in the vicinity of VC 29b discussed above, depends on whether the

palaeochannel features can be regarded as representing the deeper channels of extensive tidal flat environments, within a landscape of low topographic variation at this time, or if the features may be interpreted as estuarine channels within a mosaic of areas of higher land. The former scenario would indicate that local human activity would be significantly restricted even if the date for full inundation was relatively late, whilst the latter would imply the survival of areas of dryland, which may have thus remained exposed and possibly accessible to early Neolithic peoples.

Investigating these issues further is hampered by two main problems. Firstly, high resolution topographic data for the areas around the sampling sites are lacking and secondly, the

emplacement of the southern North Sea has subsequently eroded an unknown extent of substrate (e.g. see Figure 5.6.14) and estimating the extent of this loss is difficult. It is possible that in the early stages of inundation in particular, even small topographic differences might have made the difference between submerged contexts and those which could have persisted as islands for longer. Understanding these processes on a range of spatial and temporal scales across Doggerland is essential to investigate the possible character of Mesolithic, and perhaps early Neolithic activity in the area. This in turn has implications for the potential location and survival of *in situ* archaeological remains.

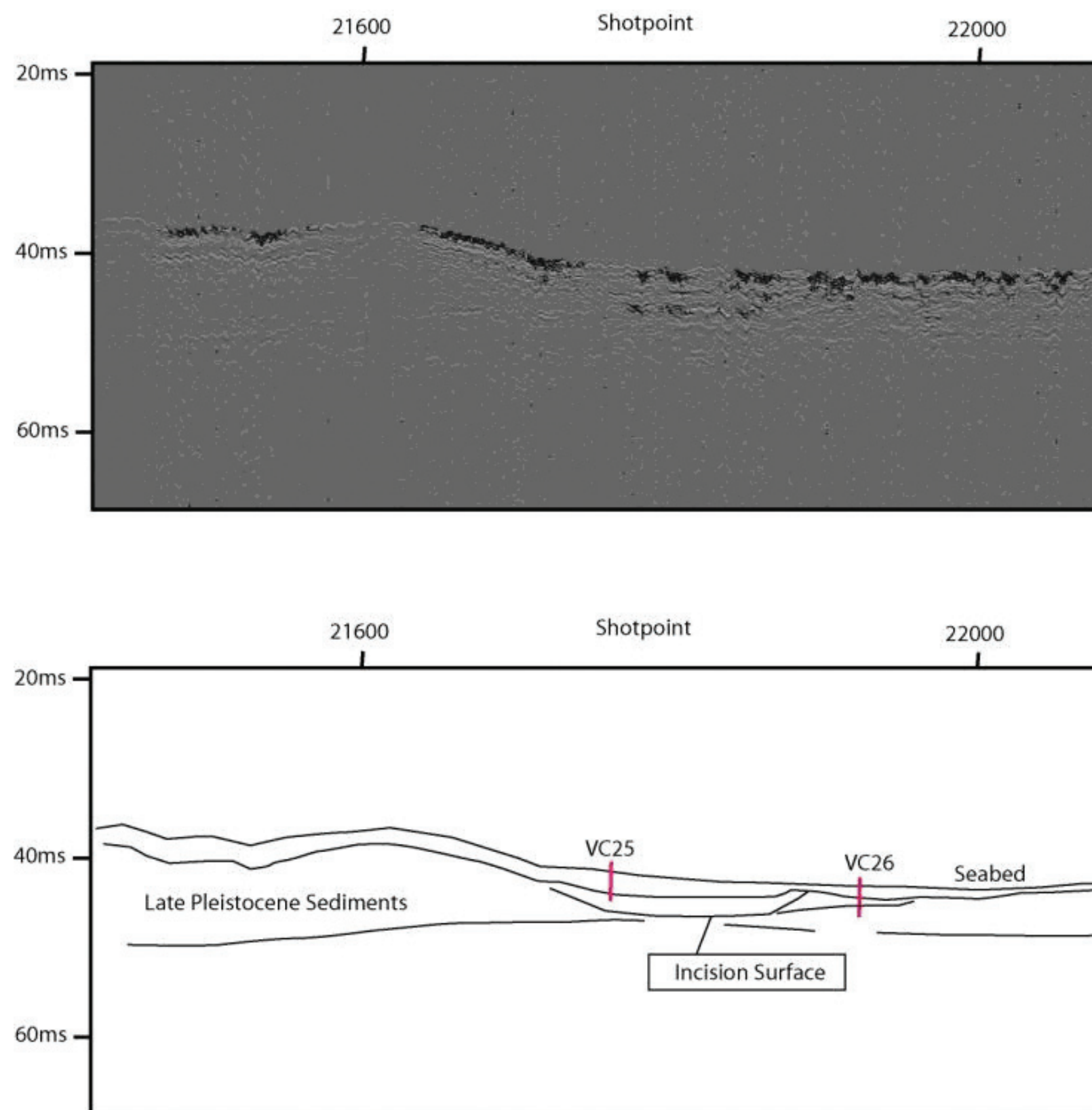


Figure 5.6.19: Coring group 5.

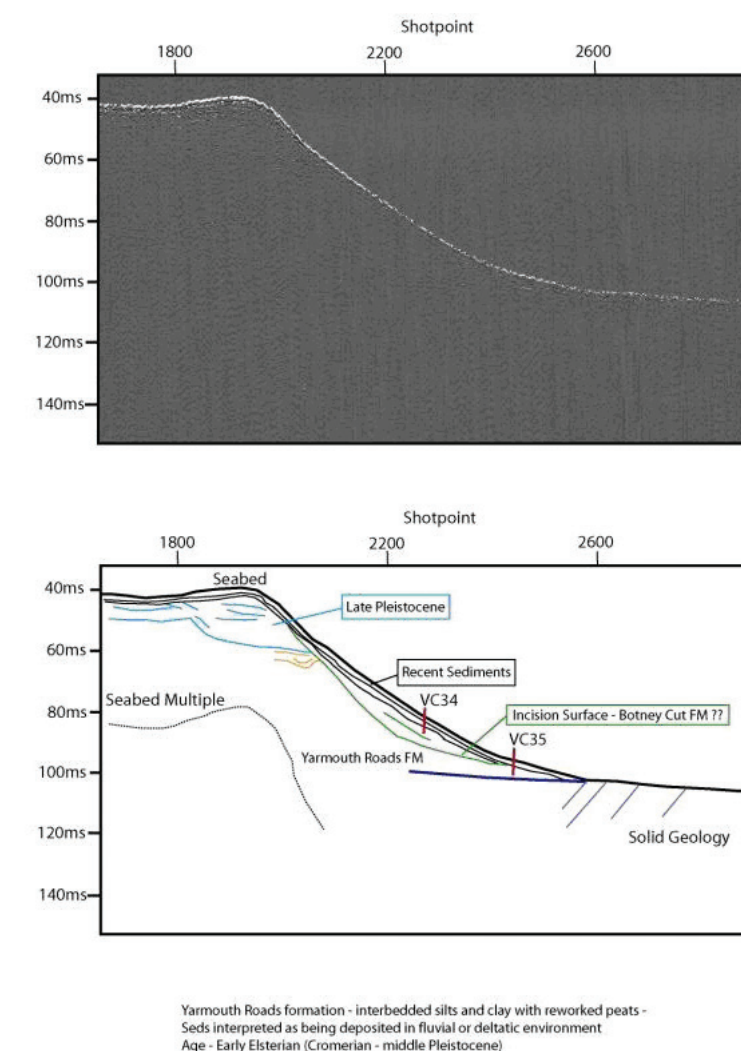


Figure 5.6.20: Coring group 7.

5.6.8 Conclusions

The combined stratigraphic information, palaeoenvironmental assessments and associated radiocarbon and OSL dating support the hypothesis that *in situ* Holocene deposits survive in the REC survey area and can be identified using geophysical data. The analyses tend to support the hypothesis that these features can generally be interpreted as palaeochannels which were incised in periods of low relative sea level. Whilst it appears that these periods of incision occurred during the Late-glacial/early Holocene period, there is some indication that certain of these features may be of greater antiquity but further work is necessary to investigate this. It appears that specific sampling sites (e.g. groups 4 and

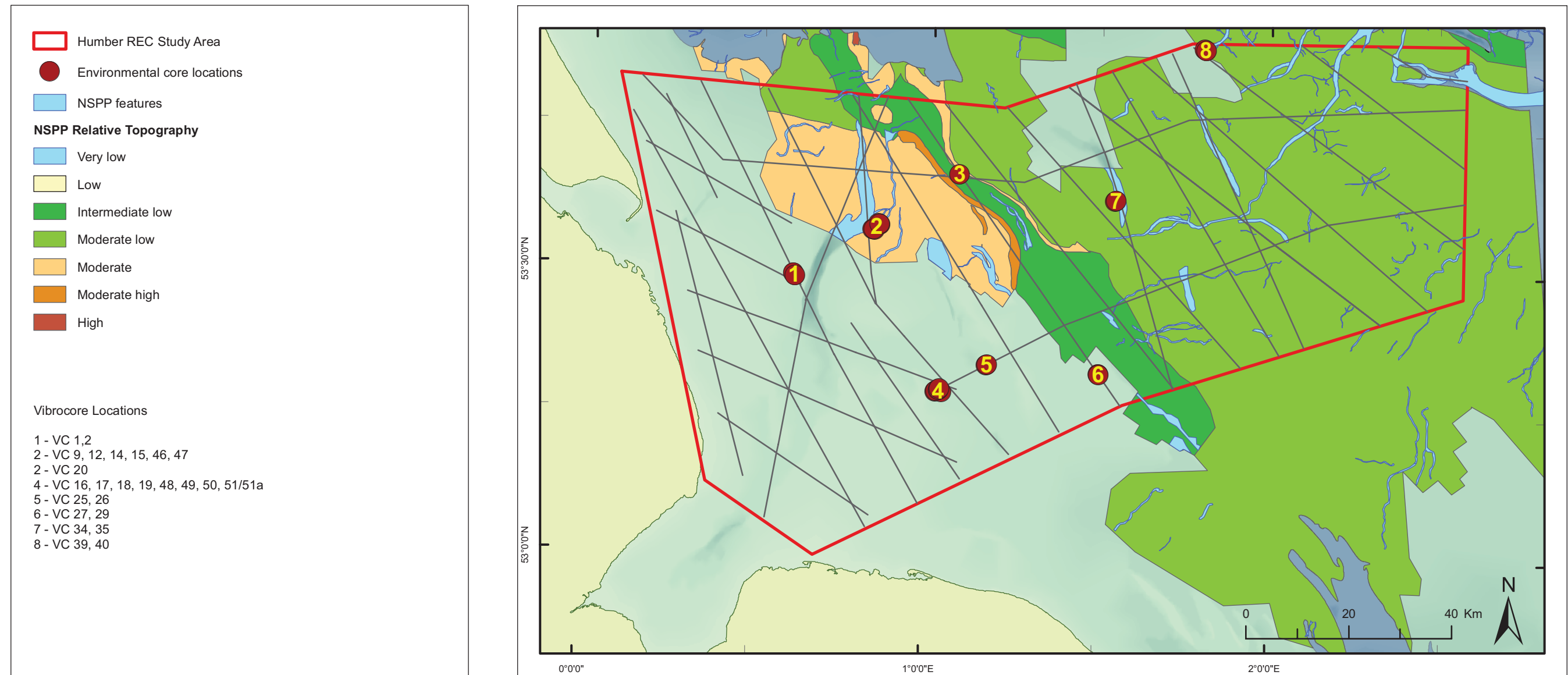


Figure 5.6.21: Timeslice (c. 10,000BP) of sealevel relative to coring locations, REC zone and interpretation of geophysical data from the NSPP (Gaffney *et al.* 2007). Sea bed contours based on BGS digibath 250K map and sea level on data from Ward *et al.* (2006; based in part on Peltier, 2004).

6) contain very similar sequences of deposits, whilst others (e.g. group 8) are characterised by sediments of similar age but somewhat different character. Some of the analyses have identified sediments that date to Upper Pleistocene contexts, but the precise character of these earlier periods of deposit formation and their relation to subsequent processes requires further investigation. It is clear that there is a high potential for further work that could shed much needed light on the spatial and temporal variation in

environmental processes operating in Doggerland across the late Quaternary in general.

Interpretation of features from geophysical data is not always straightforward and future work should seek to collect as much stratigraphic information as possible. Ultimately, this should produce a comparative database of geophysical anomalies and associated 'ground truthed' stratigraphic data which in turn will help to produce more robust interpretations. This will also assist in the

more reliable identification of sampling locations with high potential for palaeoenvironmental study.

The analysis of duplicate core sequences undertaken in this project above does suggest that the detailed analyses of single cores can be regarded as representative of a specific suite of sediments. The palaeoenvironmental and associated dating programme has thus also provided a valuable 'base line' for future offshore investigations of Doggerland. The preservation of sub-fossil proxy

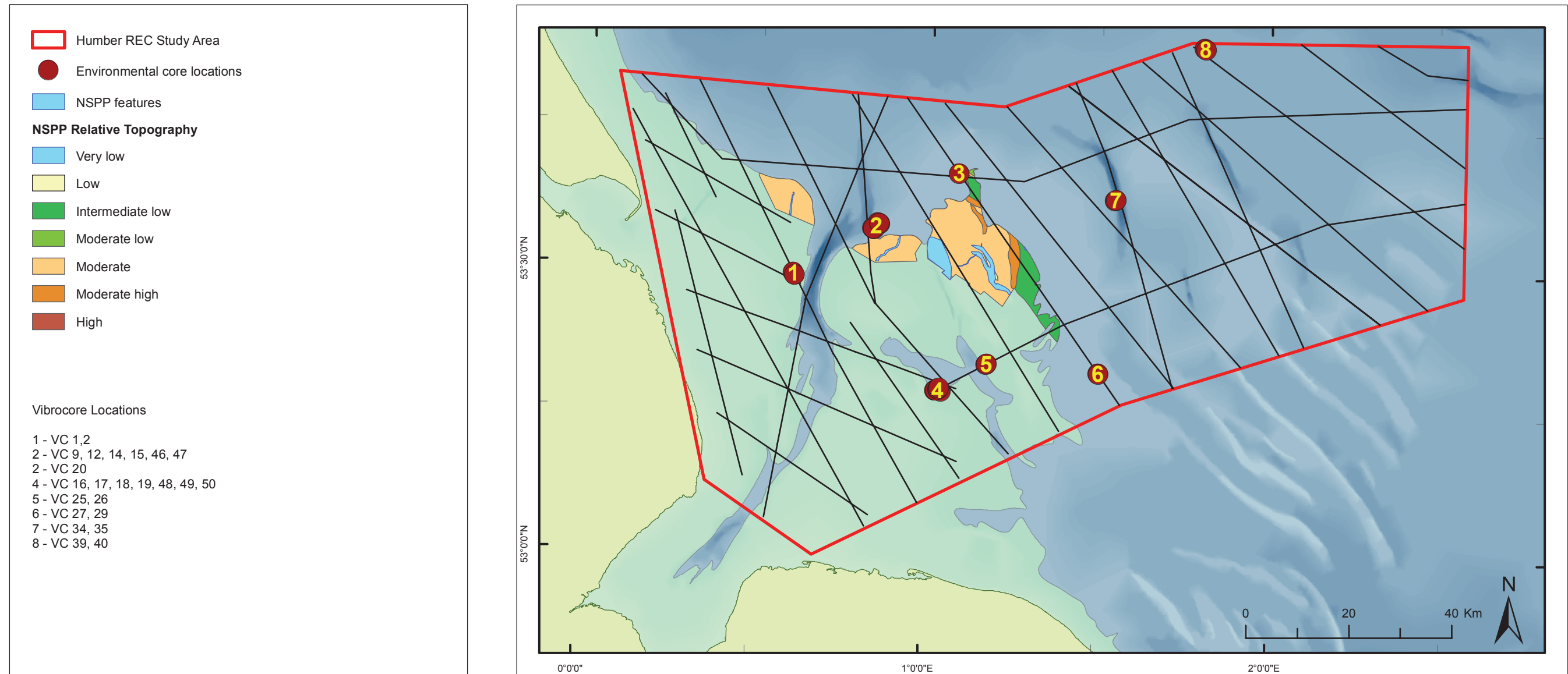


Figure 5.6.22: Timeslice (c. 8, 000BP) of sealevel relative to coring locations and REC zone.

material including plant macrofossils, beetles and pollen has been demonstrated to be very good in specific contexts. Ostracods and forams also provide valuable information regarding the character of depositional environments, but the diatom assessments indicate that problems of poor preservation may limit the utility of these proxies. Pollen was generally well preserved and in relatively high concentrations, although interpretation of these data in terms of the site specific palaeovegetation communities is problematic, given that the sampled sediments may incorporate sub-fossil

remains that have derived from a source area that includes an unquantifiable regional component.

In methodological terms, this work has also demonstrated that the establishment of robust chronologies must be central to coherent investigation of the complex spatial patterns and processes of change that characterised the inundation of Doggerland. To this end, the application of OSL dating and the modelling of these data using a Bayesian approach, has been shown to produce accurate if not especially precise chronologies for the silt/sand deposits which,

where available, appear to compare well with the radiocarbon dating results from organic units (see also Alappat *et al.* 2010). The ability to produce precise chronologies for more detailed palaeoenvironmental reconstructions is of course linked to the availability of appropriate deposits and the specific limitations of different dating methodologies.

The inevitable interpretative and taphonomic issues associated with proxy records from palaeochannel deposits have been highlighted above and there is a need for future study to identify and sample other surviving landforms with potential for palaeoenvironmental

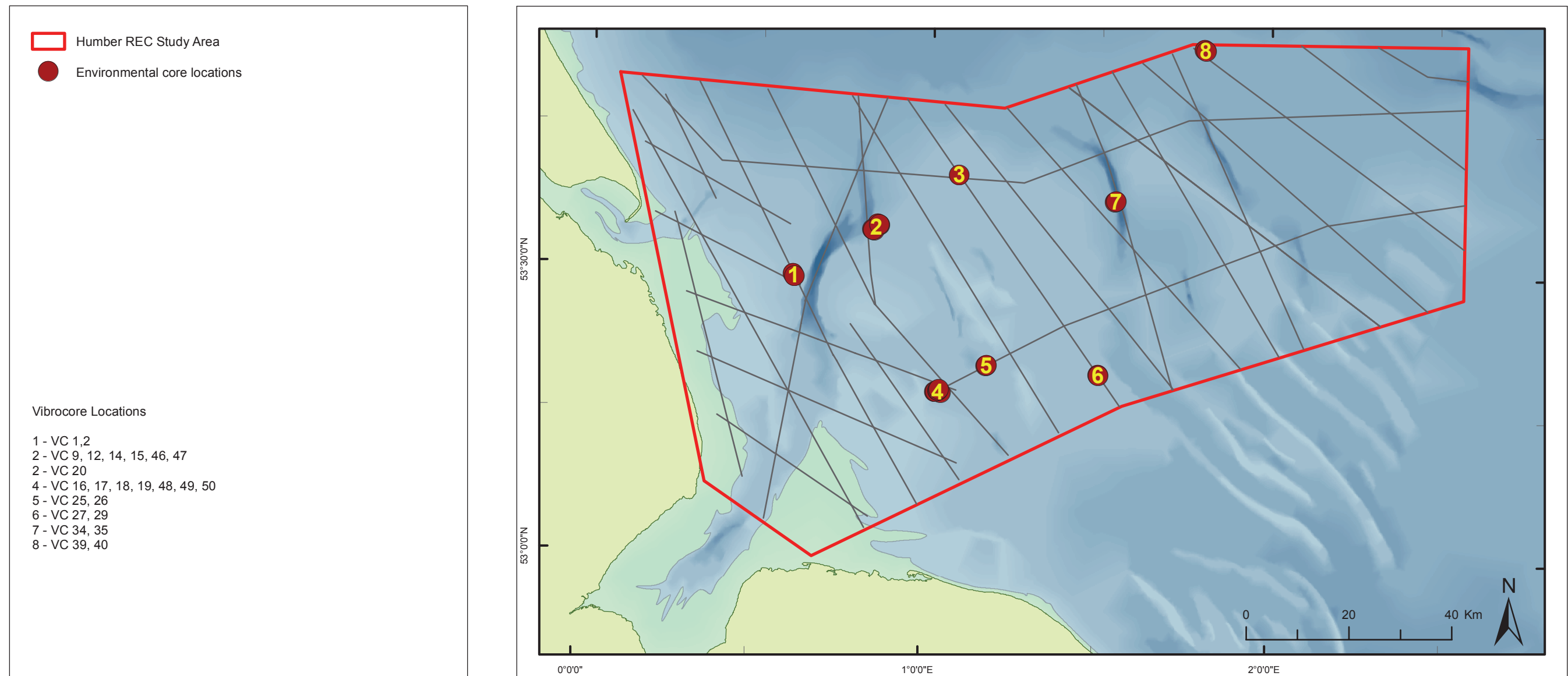


Figure 5.6.23: Timeslice (c. 6 000 BP) of sealevel relative to coring locations and REC zone.

analyses. Such features in the offshore zone may include lake basins and more extensive deposits of peat and other organic sediments, for example those associated with floodplain and other wetland environments pre-dating the marine inundation.

These and other such contexts have the potential to preserve extensive, *in situ* organic deposits which could provide more complete palaeoenvironmental records with higher chronological precision. The possibility of organic archaeological remains in wetland deposits must also be considered, although locating

and investigating any surviving features is very difficult. Although the offshore zone will continue to present a series of technical challenges to future archaeo-environmental study, it can be concluded that this work has demonstrated that the 'tool kit' to facilitate research does exist. Further investigations are now urgently required to realise the full potential of the 'hidden landscapes' of the southern North Sea.

Archive

All paper and electronic records pertaining to this project are

stored at the University of Birmingham. All remaining core samples which contain organic sediments are stored under appropriate environmental conditions in a dark refrigerator at 4°C in the Birmingham Archaeo-Environmental laboratory along with all sub-samples taken. Any cores which contained 100% sands and gravels were stored in a cool, dark laboratory.

5.7 Characterisation of the Submerged Prehistoric Landscape

It is apparent that the Study Area can be characterised into broadly

Description	Used in NSPP	Area km ²
Area of extensive Holocene landscape with numerous channel systems	NEW	2 230
Area of reuse of Pleistocene features	YES	1 570
Area of smaller Holocene Channels	YES	1 070
Area with Large Lacustrine features	YES	360
Dominated by Fluvial	YES	170
Dominated with Geology with Fluvial systems	YES	1 050
Lacustrine	YES	160
Landscape Geology Controlled	YES	1 070
Landscape influenced by underlying glacial deposit	YES	590
Low or absent Holocene cover, archaeological potential is concentrated in localised incised systems	NEW	2 770

Table 5.7.1: Landscape characterisation as defined by the Humber REC.

similar areas to that produced by the characterisation of the Mesolithic landscape performed by the NSPP (see Figure 5.7.1). However, whilst the eastern portion is largely comparable, notable modifications to the zones have been made in the nearshore areas to reflect the additional information provided by the REC assessment. The new characterisation of the Mesolithic landscape is presented in Figure 5.7.2. This is an important improvement in definition of the character areas of the nearshore zone. This however should not be surprising, since the NSPP dataset did not cover a fair proportion of this area. It is also important to observe that the characterisation produced by the survey lines taken by the Humber REC, broadly upholds the existing landscape character interpretation with respect to submerged prehistoric landscape archaeology.

Analysis of the identified features within the study area was undertaken and a characterisation was undertaken. The submerged prehistoric landscape characterisation produced by the Humber REC used 8 of the existing 14 categories defined by the NSPP (see Table 5.7.1 below). However, it is significant that this work required the creation of two additional categories or landscape zones to complete the classification of the whole of the study area. Of the 312 features or areas in total identified from

Description	Area Km ²	Total of LENGTH Survey Lines	Number of Features / landscapes Identified along lines	Length of Features/ landscapes along lines	Projected Percentage of Character area containing Holocene features/landscape (km ²)
Area of extensive Holocene landscape with numerous channel systems	2233	323	172	46.1	14% (319 km ²)
Area of reuse of Pleistocene features	1567	270	34	11	4% (64 km ²)
Area of smaller Holocene Channels	1074	148	13	4.6	3% (33 km ²)
Area with Large Lacustrine features	356	53	9	3	5% (20.15 km ²)
Dominated by Fluvial	167	25	1	0.06	0.2% (0.4 km ²)
Dominated with Geology with Fluvial systems	1052	138	9	1	0.7% (7.6 km ²)
Lacustrine	158	81	5	0.1	0.1% (0.2 km ²)
Landscape Geology Controlled	1074	203	5	0.9	0.4% (5 km ²)
Landscape influenced by underlying glacial deposit	591	120	22	5.8	5% (29 km ²)
Low or absent Holocene cover, archaeological potential is concentrated in localised incised systems	2770	464	35	8.5	2% (51 km ²)

Table 5.7.2: Humber REC character areas and projected percentage of Holocene features/landscape.

the geophysical surveys, therefore, 69 were used to refine and reclassify the previous landscape characterisations, 139 features were used to characterise areas previously uncharacterised, whilst 94 were used to corroborate and enhance the existing classifications. This represents an important addition to our scientific and archaeological knowledge in this area.

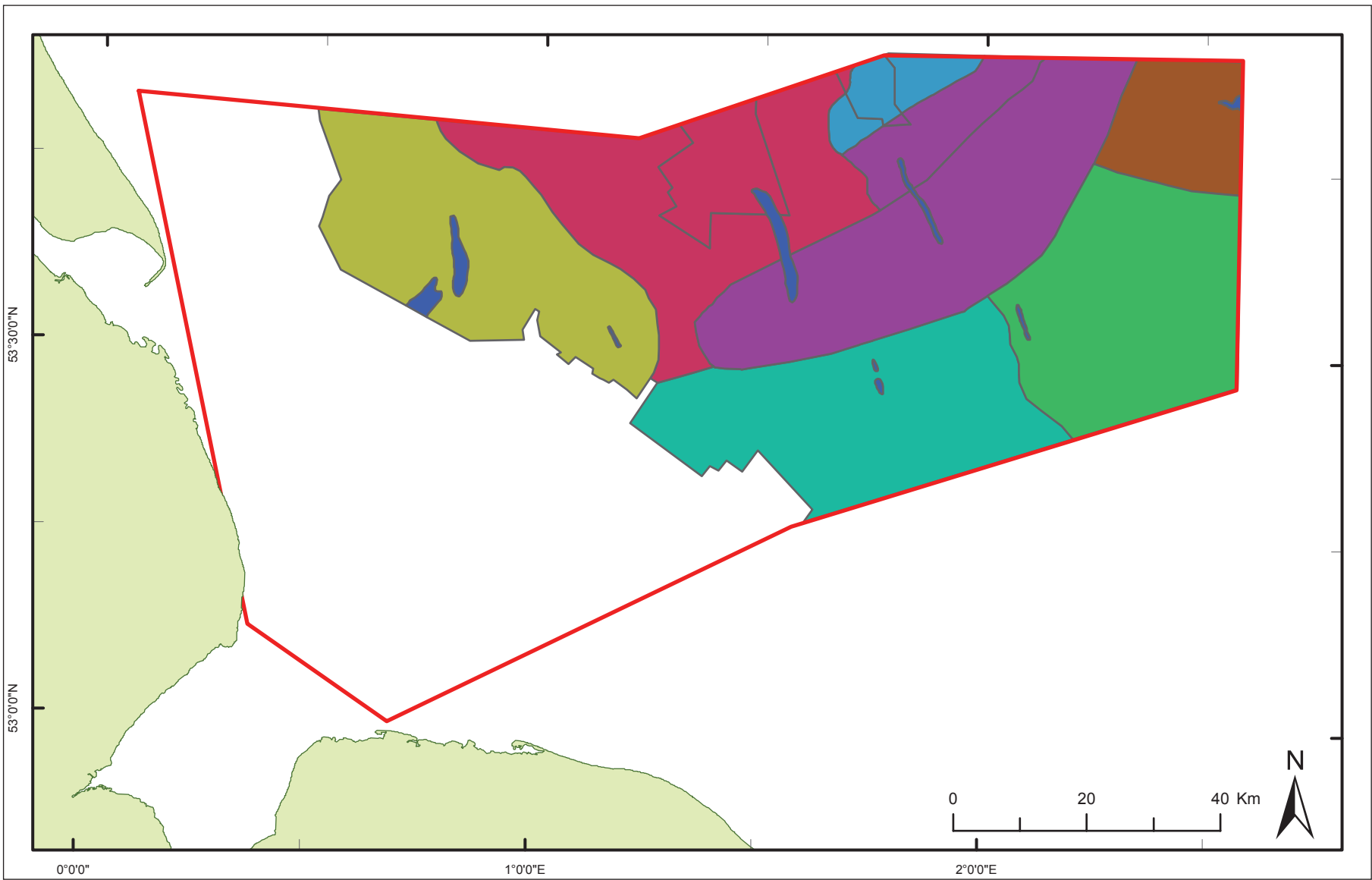
The Humber REC study area represents some 11221 km² to be characterised with respect to its submerged prehistoric landscape. 6548 km² of this area was previously characterised by the NSPP, however through the utilisation of the Humber REC results 1150 km² of this area was re-classified. Of the remaining 4672 km² of the study area, new landscape characterisation data has now been provisioned (Figure 5.7.3). If the Humber REC characterisation dataset is added to that already existing for the NSPP, the total area of the Southern North Sea characterised in this fashion can be seen to have increased by some 17.8%. This major increase in knowledge of the archaeological resource is a direct result of data provision from the Humber REC.

Within the areas already characterised by the NSPP, some 103 Holocene channels and 37 areas relating to Holocene land surfaces

were located by the Humber REC project. These were utilised to corroborate the existing characterisation, and where necessary facilitated a reclassification. In the areas not covered by NSPP data some 120 areas containing archaeologically significant landscape features and 47 areas of Holocene landscape were identified and were utilised to assist the classification of new areas (Figure 5.7.4).

Perhaps the most archaeologically significant area identified was a dense cluster of channels and landscapes that was found in the south of the Study Area which required the creation of a major new character zone (Figure 5.4.4). A small part of this zone had been covered by the low resolution part of the NSPP dataset and was previously characterised as 'Landscape Influenced by Underlying Glacial Deposit'. However due to the presence of over 31 Holocene channels and 22 areas of Holocene land surface identified within the new higher resolution information provisioned by the Humber REC this area was reclassified as an 'Area of Extensive Holocene Landscape'.

This newly identified character zone was extended to the west by adding a further nearby region of previously unclassified landscape. This was also identified as 'Extensive Holocene



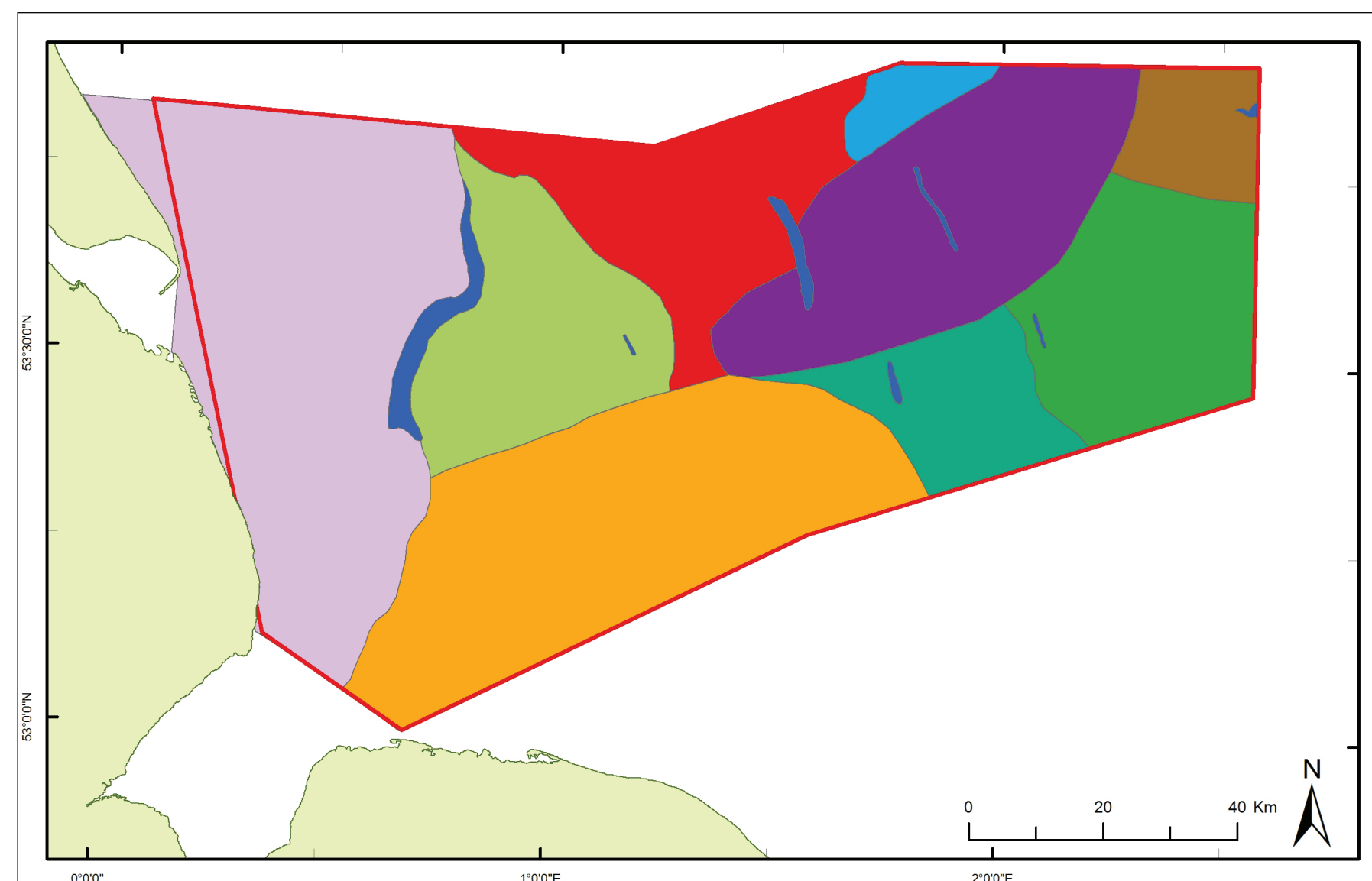
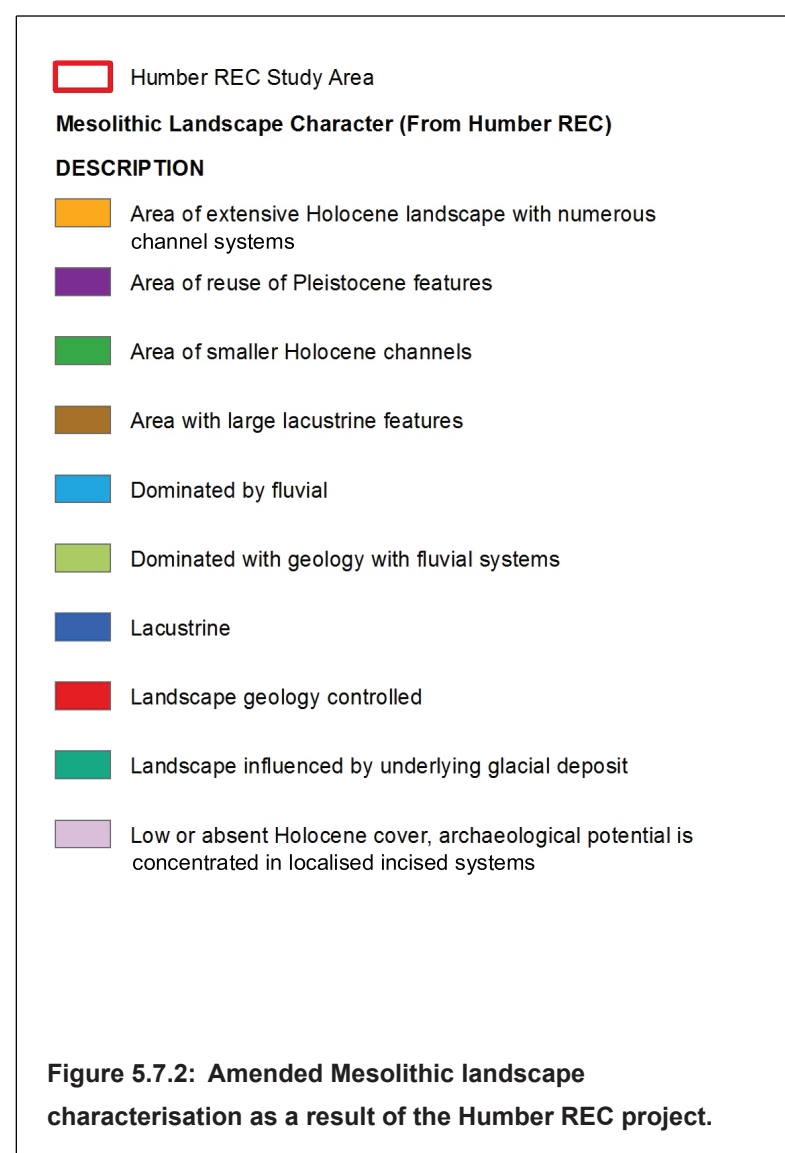
Landscape' due to its high density of channels and landsurfaces from the Humber REC geophysical datasets.

To gain an understanding of the possible distribution of archaeologically significant Holocene features within the character zones, further investigation was undertaken. By utilising the area of survey covered by the geophysical lines it becomes possible to approximate the density of archaeologically significant landscape features within each of the character zones. The sum of the survey lines (not taking into consideration multiple passes) was approximately 1300 km for the outer area, and 530 km for the inner area.

Through the consideration of the line density as a proportion of the study area, and the density of Holocene features within it, it was possible to provide an approximate density of cover which could be expressed as a percentage. This information for each character area is presented in Table 5.7.2, in addition to the number of features identified and survey line lengths. These allowed for a further re-evaluation of the previous landscape characterisation, and the consideration of the potential for Holocene features and landscapes to be present at a finer level of detail than was previously realised.

5.8 Human Impacts in the Region

As identified in Chapter 2, Regional Perspectives, the Humber REC area has been subject to major developmental activity in the form of fishing, hydrocarbon exploration and development, aggregate dredging and wind farm construction. All of these have had a major impact on the seabed. Interpretation of the Humber REC geophysical data set, mainly MBES, SSS and backscatter reveals anthropogenic impacts in the form of dredging scars associated with aggregate exploitation, trawl-marks from commercial fishing activity, and exposed gas pipelines linking the development platforms and these platforms with the shore



(Figure 5.8.1). The width of the geophysical corridors along which data were acquired are narrow (100's of metres) in relation to the Humber REC area, thus the locations and areas of the features mapped are necessarily very limited. Despite the limitation in data coverage, we do attempt to give a regional impression of the human impacts from resource development on the seabed within the Humber REC area. The details of the features mapped are best observed in the accompanying GIS.

5.8.1 Dredge Scars

Dredge scars are limited to the licensed dredging areas. The

locations and areas of the mapped features are considered conservative because of sedimentation after they were formed. We have not mapped isolated dredge scars, but only areas where there is clear evidence of systematic dredging.

5.8.2 Trawl Marks

Areas where trawl marks are common were mapped. Trawl marks are mainly present in the east of the REC area, reflecting the intensity of fishing activity here, as well as the preservation potential of the scars in the seabed sediment.

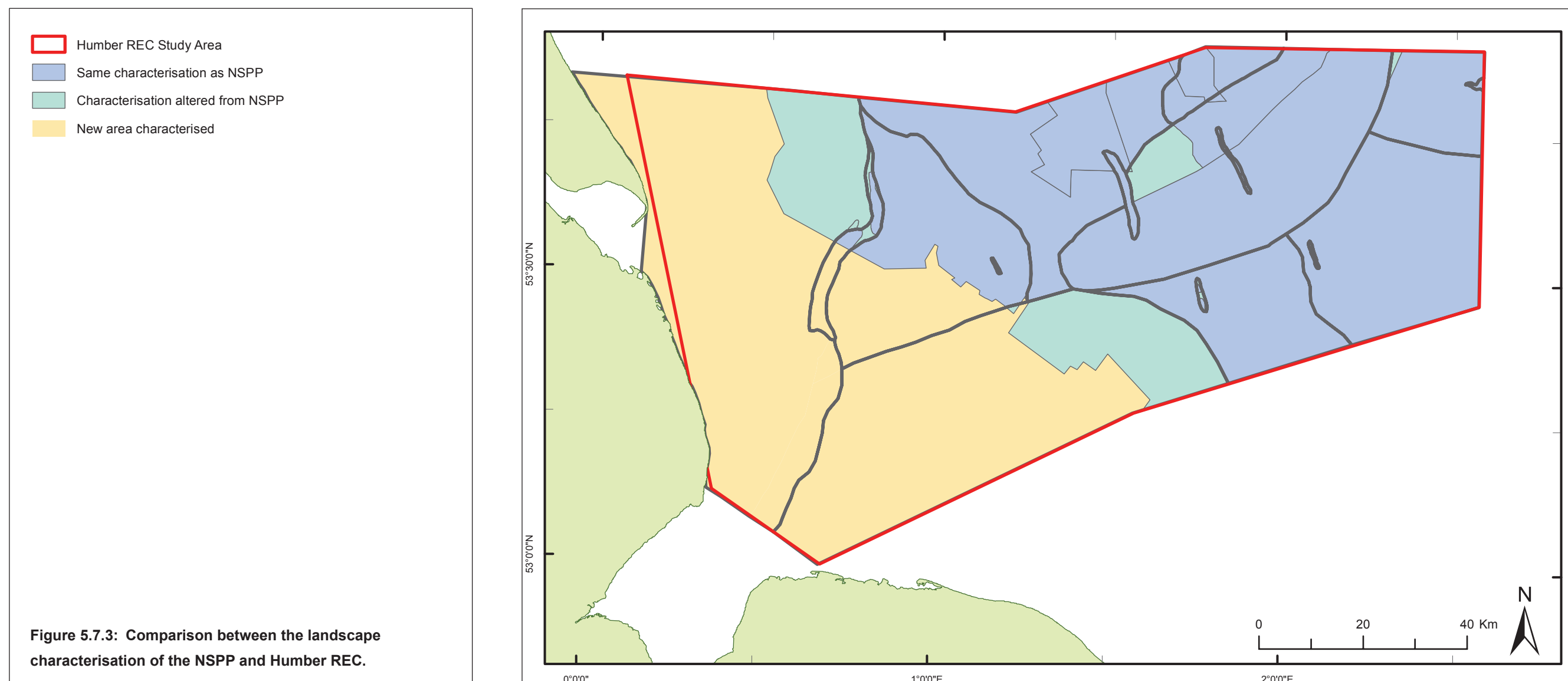
5.8.3 Pipelines

Pipelines are mapped where observed exposed at seabed as well as where seabed morphological features, such as linear scars or linear sediment accumulation, are present that indicate burial beneath mobile sediment.

5.9 Archaeological Conclusions

5.9.1 Prehistoric Archaeology and Landscapes

The survey of the Humber REC region has utilised a combination of geological, geophysical, and archaeo-environmental data to delimit



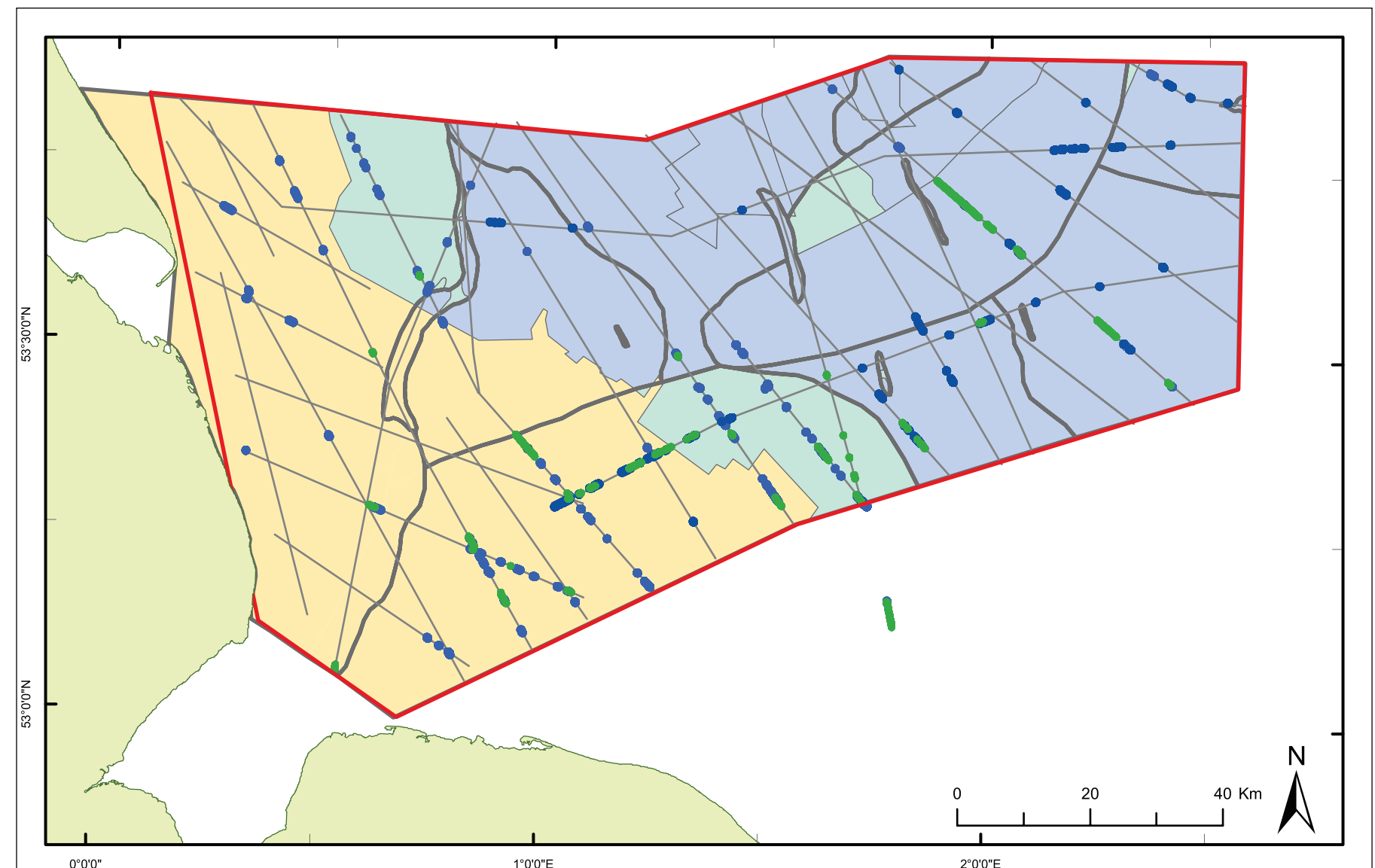
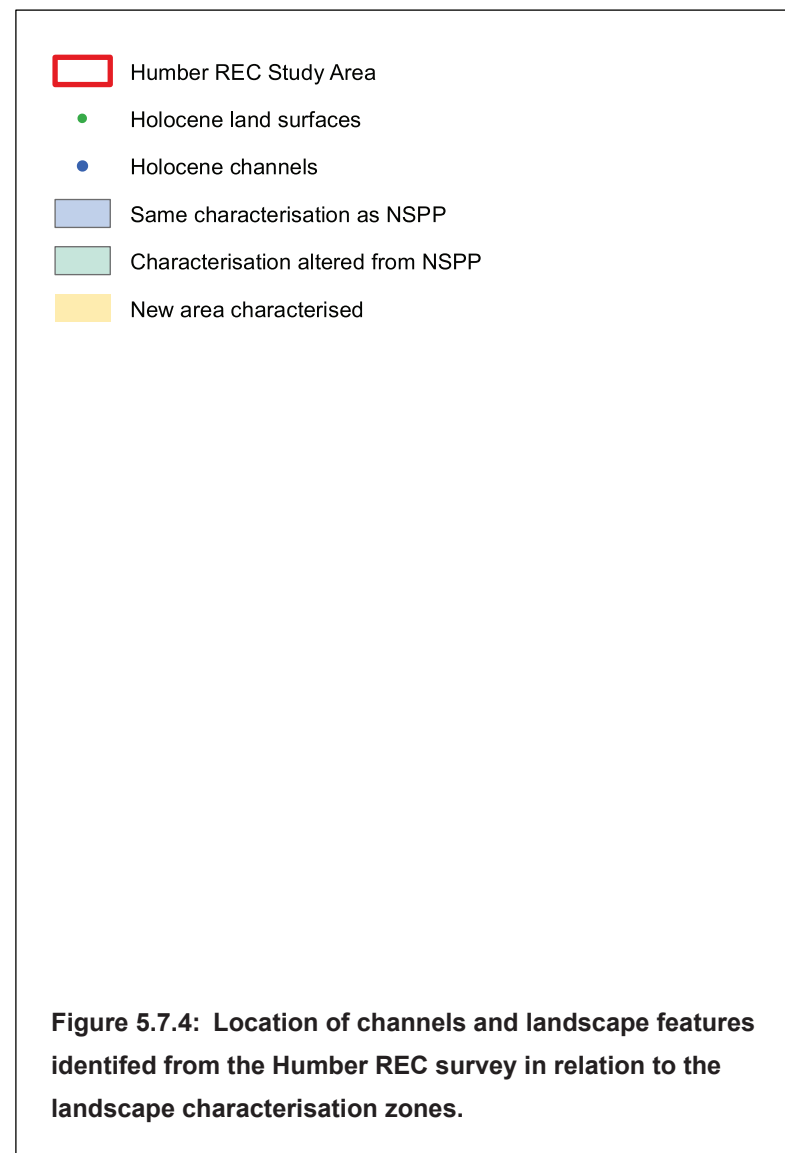
areas of higher archaeological potential. The geophysical survey of the Humber REC area and its associated coring programme has provided significant new information regarding the nature and extents of deposits which may potentially preserve archaeological sites and finds. Whilst due to the limitations of the survey coverage, it has not been possible to produce a definitive map of this landscape; significant advances in knowledge have been achieved.

Whilst the precise location of any prehistoric sites offshore is currently unknown, the geophysical survey of the REC has significantly expanded our knowledge of the submerged prehistoric landscapes of this region. In addition the stratigraphic

and palaeoenvironmental data derived from the 'ground truthing' phase of the project has provided essential information regarding the age and character of *in situ* deposits. The analytical phase demonstrates that Holocene and earlier deposits are preserved generally in palaeochannel contexts, and that these sequences have the potential to provide information regarding patterns and processes of past environmental change. Given the rarity of such material, this information can be regarded as of high national and international importance.

The survey has highlighted both the south and eastern areas of the Humber REC study as possessing archaeologically significant

landscape features; whilst those in the west closer to the current coastline have much thinner deposits which are less likely to preserve material. The REC data shows that the southern area in particular preserves significant proportions of features of the Mesolithic landscape intact, and this has been supported by the coring and associated analytical programme. However, given the probable relatively limited extent of archaeological sites in proportion to the area of study, any such archaeological finds are likely to be through chance. Nevertheless, the improvement in knowledge of the character and extent of the archaeological landscape can be regarded as ultimately highly beneficial to the



development and management of the offshore resource (Flemming 2002, 41).

5.9.2 Maritime Archaeology

The results of the Humber REC survey have assisted in improving the understanding of the density of maritime archaeological materials on the seabed. Such data will be invaluable in improving and updating datasets such as the NMR and UKHO, with the survey having identified additional sites not currently recorded in either of these two databases. Without diver survey it is impossible to ground truth these results. Additionally, other debris, possibly

material or cargo losses have been identified within the data, but again without ground truthing it is impossible to determine the precise character of this material.

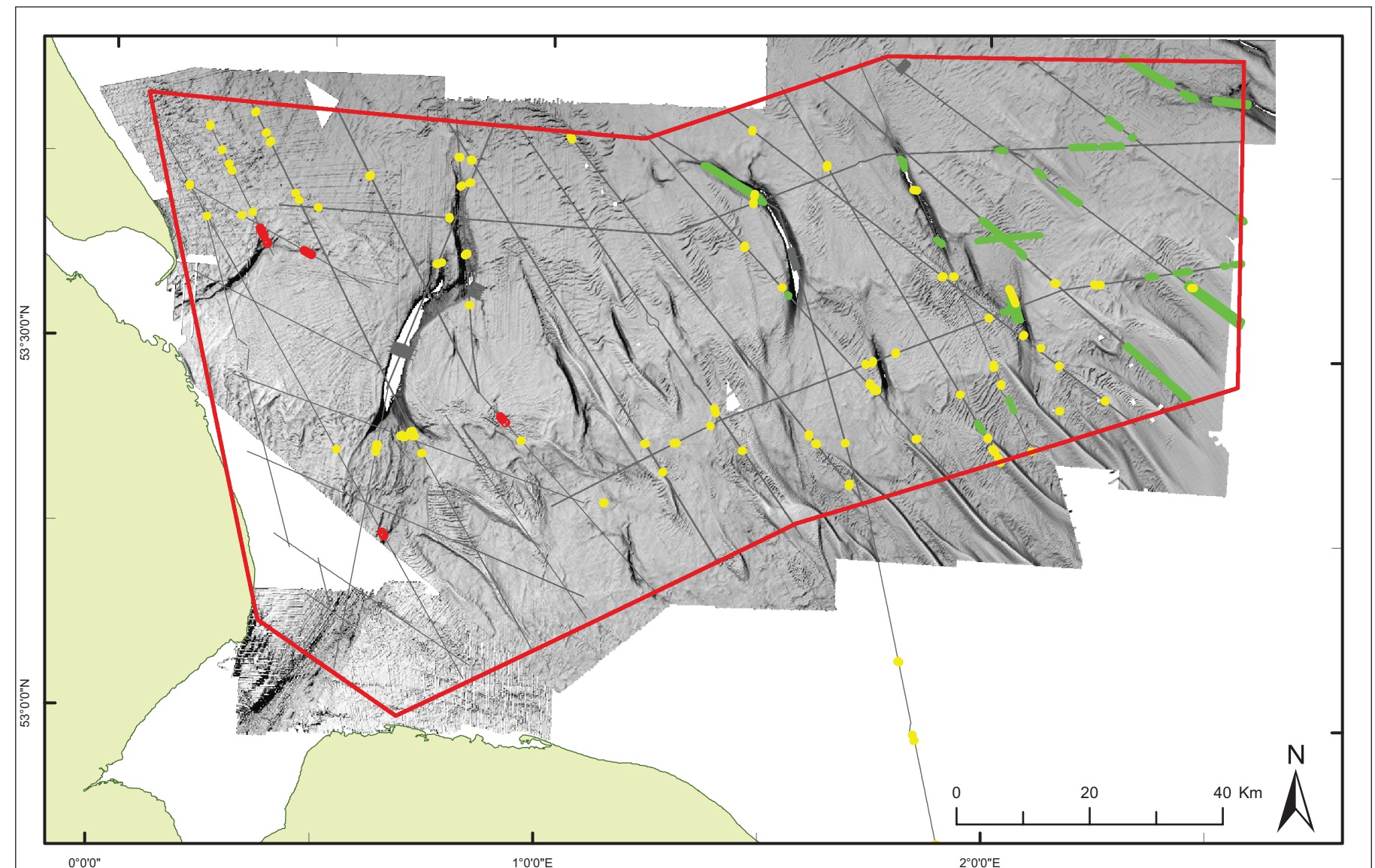
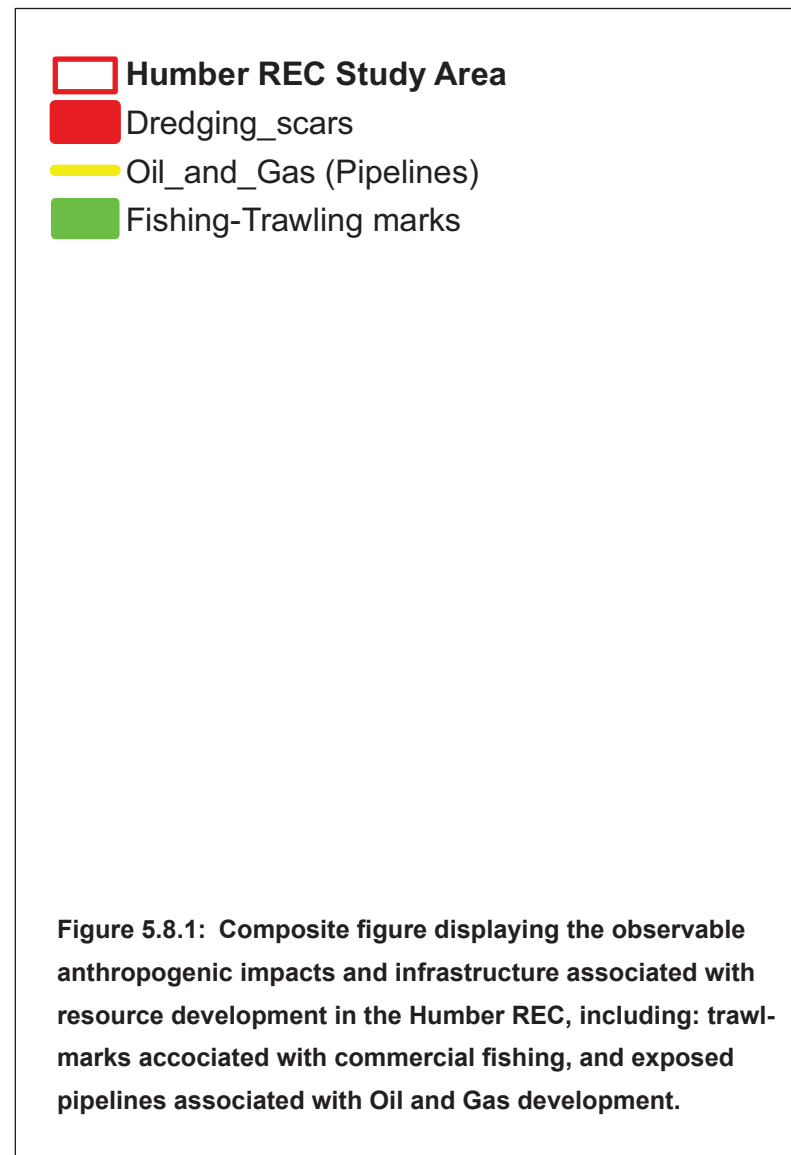
Of the identified vessels, all date from the late 19th century through to more recent times, with earlier periods not being represented within the results due to the ephemeral nature of such remains. This prevents any meaningful conclusions from being drawn about the distribution of this material.

Considering the 19th century to more recent wrecks, the strongest distribution correlation is with anthropogenic (e.g. WW2 mine

fields — see section 5.3) rather than environmental factors. However, it is noted from work by Merritt *et al.* 2007, that the seabed sediment type does have an impact upon wreck preservation. However, given the limited coverage of the survey lines in respect to the entire study area it is not possible to provide firmer conclusions.

5.9.3 Aviation Archaeology

Examination of the available databases for aircraft wrecks reveal that location information is very meagre and for the majority only approximate at best. The distribution of aircraft wrecks within the



Humber REC region is therefore unclear and given Humber's importance as a key target during WW2 the number of wrecks is highly likely to be an underestimate.

Given the relatively small size and fragility of aircraft wrecks it is perhaps not surprising that these were not identified during

the survey. However it is possible that some of the unknown geophysical anomalies identified during the survey represent aircraft wrecks.

5.9.4 Human Impacts in the Region

Main human impacts in the Humber REC area are dredge scars, trawl marks and gas pipelines. These have been mapped from the MBES, SSS and backscatter.

6 Biological Characterisation

The living resources in the Humber REC study area were sampled using a combination of sampling gear (Chapter 3). A 0.1 m² mini Hamon grab was used to collect quantitative samples of the benthic macrofauna living within and on the surface of the seafloor. Larger epifaunal animals living on the surface of the sea bed, including mobile invertebrates and demersal fish, were sampled using a 2 m scientific beam trawl. Further information about the seabed habitats present was collected using underwater imagery. The biological communities sampled across the Humber REC area using these three methods are described below.

6.1 Benthic Macrofauna

Collectively, the benthic macrofauna sampled across the area were relatively rich and the overall diversity was comparable to habitats sampled in regional assessments of the South Coast and eastern

English Channel (James *et al.*, 2007 & 2010) with a total of 684 taxa recorded across 135 samples. Annelida accounted for over 30% of the total number of species in the Humber REC study area. There were fewer Crustacea, Mollusca and Miscellaneous phyla (including colonial hydroids and bryozoans) and relatively few echinoderm species. Molluscs and Miscellania (mostly cnidarians) dominate the benthos in terms of weight (Figure 6.1.1), each accounting for 29% of the total biomass recorded (g Ash Free Dry Weight, g AFDW).

Figure 6.1.2 shows the eleven most abundant species recorded in grab samples taken across the Humber REC study area. There was a mixture of encrusting fauna, including barnacles, ascidians (sea squirts) and tubiculous polychaetes, and infaunal animals including bivalve molluscs and amphipod crustaceans which reflects the diversity of seabed habitats found in this area.

The barnacle *Balanus crenatus* (Crustacea) was the most abundant species with a total of 10 129 individuals recorded.

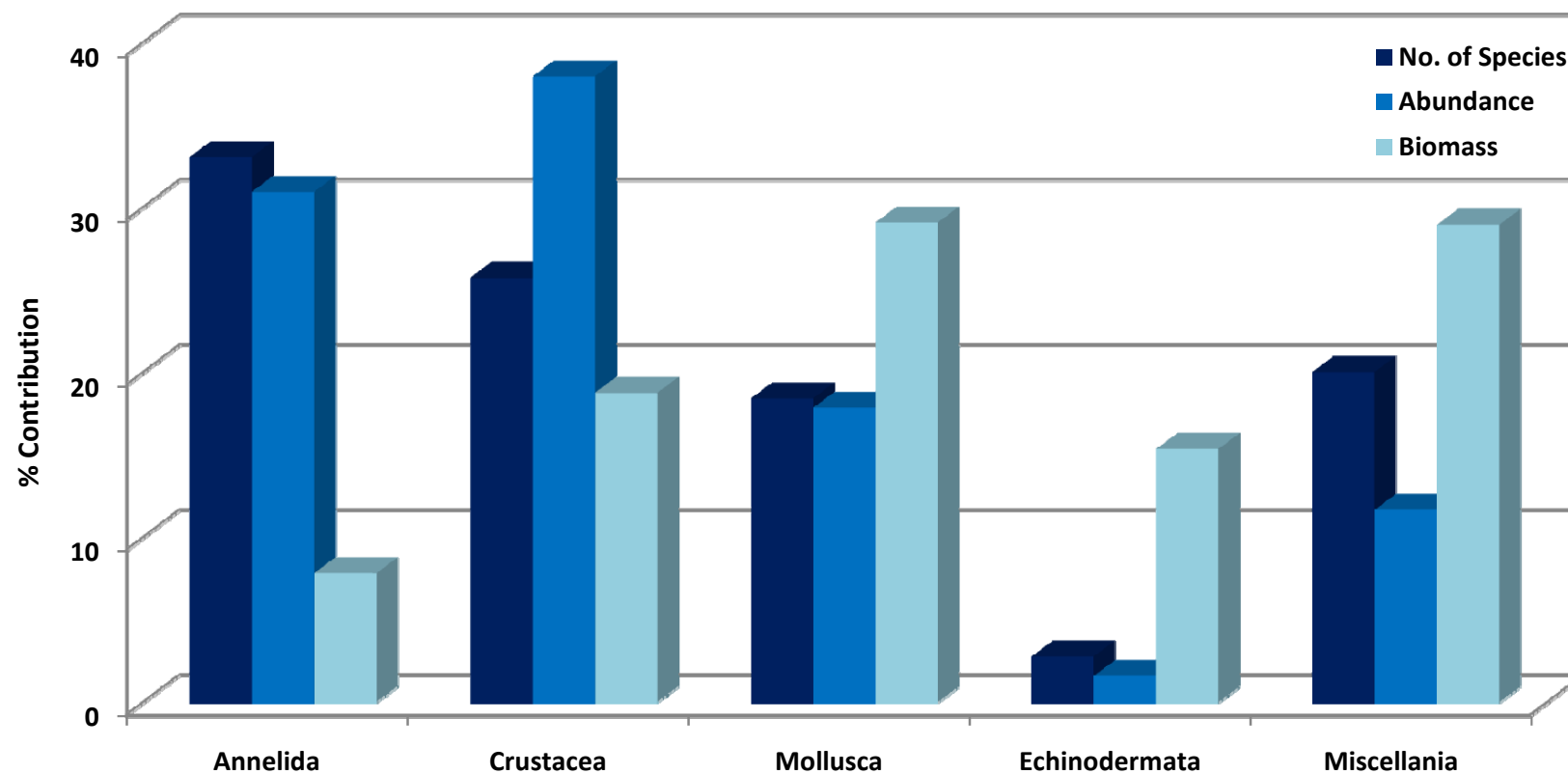


Figure 6.1.1: Relative contributions of major phyla to the number of benthic species (diversity), abundance and biomass (g AFDW) recorded from 0.1 m² Hamon grab samples taken across the Humber REC study area.

B. crenatus is one of the most common sublittoral barnacles in the UK colonising a wide range of substrata. The third most abundant taxon recorded was Cirripedia, with an additional 4,656 barnacles that were too small or damaged to identify reliably. The gregarious settlement behaviour of barnacles (Miron *et al.* 1996) means that high abundances are not uncommon in areas where suitable attachment surfaces are readily available (Kenny and Rees, 1994).

The Ross worm, *Sabellaria spinulosa* is most often encountered as solitary individuals or in small clumps (Pearce, 2009). However, this species can form extensive reef structures which have been identified as a conservation priority at a European level, and as such are listed under Annex I of the EC Habitats Directive (Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora). Like other sedentary organisms, *S. spinulosa* is thought to require a hard substratum upon which to settle and build its tubes (Holt *et al.* 1998). However, once a colony has established, it is possible for the sand structure to increase in extent without a requirement for further hard substrata (Gruet & Bordeur, 1995). This facilitates the development of *S. spinulosa* aggregations in a variety of environmental conditions including areas of mobile sand (George & Warwick, 1985). *Sabellaria spinulosa* was the second most abundant species recorded in the Humber REC area, indicating that significant reef structures are likely to be present in this region.

The bivalve *Abra alba* is a characteristic inhabitant of muddy fine sand or mud substrates and it is often particularly abundant at water depths of around 20 m (Tebble, 1976). This species has a widespread distribution around the UK and much of Europe and is often associated with highly diverse and abundant communities (Van Hoey *et al.* 2004). Dense aggregations of *A. alba* are likely to be of some ecological significance, possibly serving as a food resource for sea ducks and demersal fish (Degraer *et al.* 1999).

Other abundant species include acidians, or sea squirts, such as *Dendrodoa grossularia*, the tubiculous polychaete *Pomatoceros lamarckii* and juvenile mussels (Mytilidae). These animals are widely distributed around the coast of the UK and are often found in high abundances where attachment is available and environmental conditions are suitable (Kenny & Rees, 1994). Also common across the area is the burrowing amphipod *Urothoe elegans* which is typically found in sandy sediments (Eleftheriou & Basford,

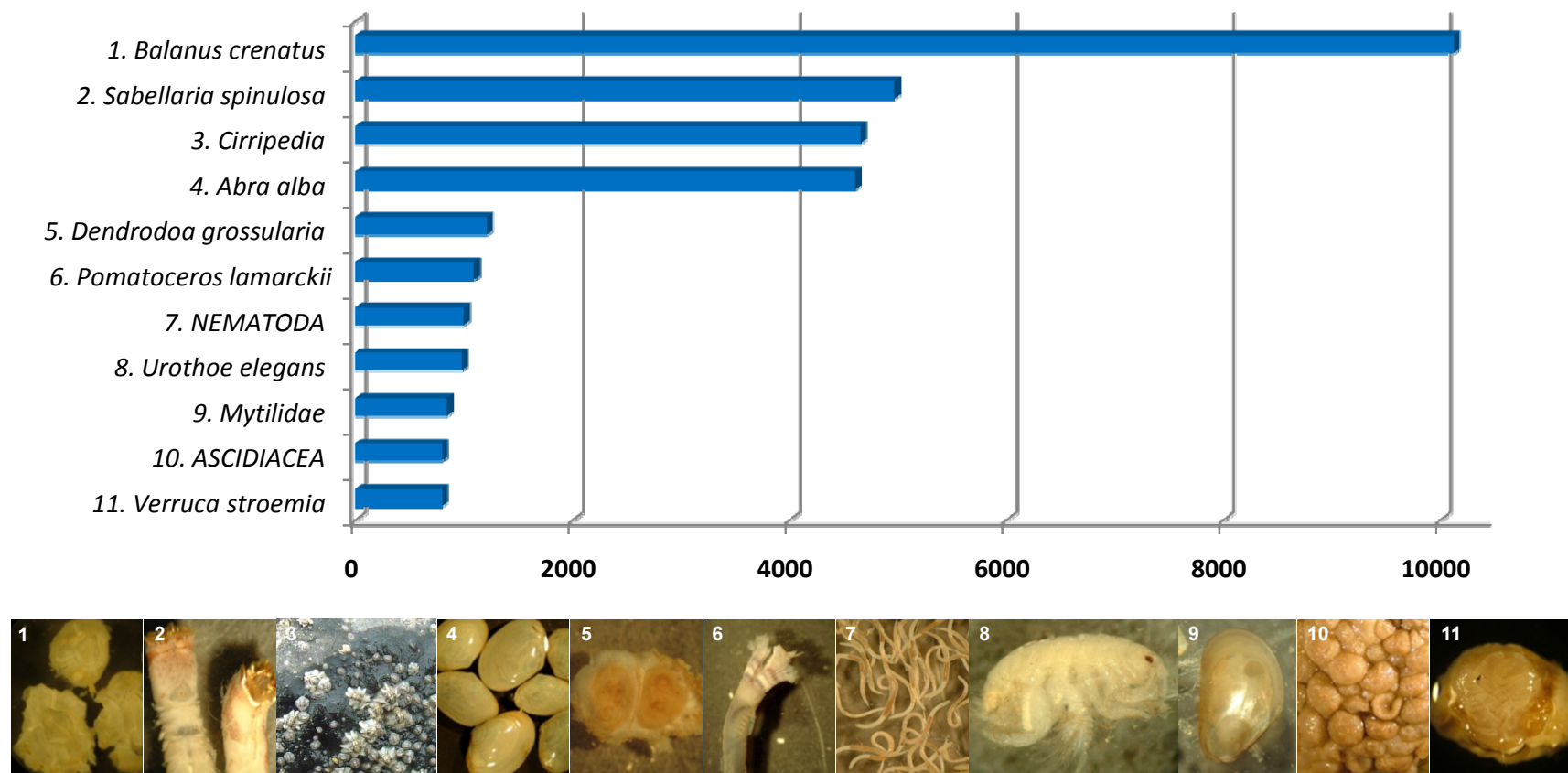


Figure 6.1.2: Total abundance across 135 samples of the eleven most abundant species recorded in 0.1 m² Hamon grab samples taken across the Humber REC area. Photographic images of these species are also shown.

1989) along with free-living nematode worms which also inhabit sedimentary environments. The taxonomic diversity of dominant species present across the Humber REC study area is indicative of the complex and wide ranging environmental conditions that occur.

6.1.1 Spatial Patterns in Benthic Macrofaunal Composition and Diversity

The number of species, the abundance and biomass (g AFDW) of benthic macrofauna extracted from each of the Hamon grab samples are presented in Figures 6.1.3–6.1.5. These measures of the community composition show a general gradient with distance from the shore with higher diversity, abundance and biomass of benthic fauna in the inshore half of the study area. There is a good correspondence between abundance, biomass and diversity across the REC study area and the sediment regime present (see

Figure 4.2.29 sediment map), indicating that the sands of the eastern half of the study area supports a much sparser benthic fauna than the mixed sediments in the west.

To further investigate patterns of biological diversity across the Humber REC study area a number of standard diversity indices were calculated for each of the grab samples (Figures 6.1.6–6.1.8). The first of these, Simpson's Diversity Index ($1-\lambda$) is derived from the number of species present as well as the relative abundance of each species. A high Simpson's Diversity Index (approaching 1) indicates high biodiversity which is a high number of species and evenness in the abundance of those species. The majority of grab samples (> 80%) had an Index between 0.70 and 1 (Figure 6.1.6) indicating a relatively high biodiversity of benthic macrofauna. There were a small number of grab samples in the central and inshore areas that had a low (<0.5) Simpson's Diversity

Index indicating low biodiversity because the total abundance was dominated by a small number of species. These samples also tend to have a low Pielou's Evenness Index (Figure 6.1.7).

Figure 6.1.7 shows the relative evenness (Pielou's Evenness, J') of the macrobenthic communities across the Humber REC study area. Evenness is a measure of how similar species are in their abundance. A high evenness value (approaching 1) indicates that the majority of species are equally abundant. Conversely a low value indicates that one or more species dominates the community. The majority of grab samples from the area exhibit high evenness but areas of lower evenness (<0.7) are observed in a number of locations, particularly in the inshore area indicating that the abundance of animals is not evenly spread amongst the different species found here.

Taxonomic Distinctness (Δ^*) describes the average relatedness of species in a sample. In this case a sample in which species are distributed amongst several families will be more diverse than a sample with identical richness and relative abundance, where species originate from the same family or genus (Warwick and Clarke 2001). This is perhaps the most useful and instinctive measure of biodiversity. Taxonomic Distinctness is high across much of the Humber REC study area with over 90 % of grab samples having a Taxonomic Distinctness value higher than 80, further highlighting that the study area supports a high diversity of benthic macrofauna (Figure 6.1.8). Lower Δ^* values are observed at a number of stations spread across the whole of the Humber REC study area. It is likely that the environmental conditions in these locations are such that some taxonomic groups are excluded, for example an absence of coarse sediments would exclude some phyla such as ascidians which are wholly epifaunal.

There is little correlation between the number of species recorded across the Humber REC area (Figure 6.1.3) and the three calculated diversity indices, Simpson's Diversity, Pielou's Evenness and Taxonomic Distinctness. This is because although there was a much higher number of species recorded in the western half of the study area, these communities are numerically dominated by one or a few species. This disparity also indicates that whilst the eastern half of the study area supports a very sparse benthic community, the species that were there were as diverse in their taxonomic structure as those in the inshore areas. It is likely then

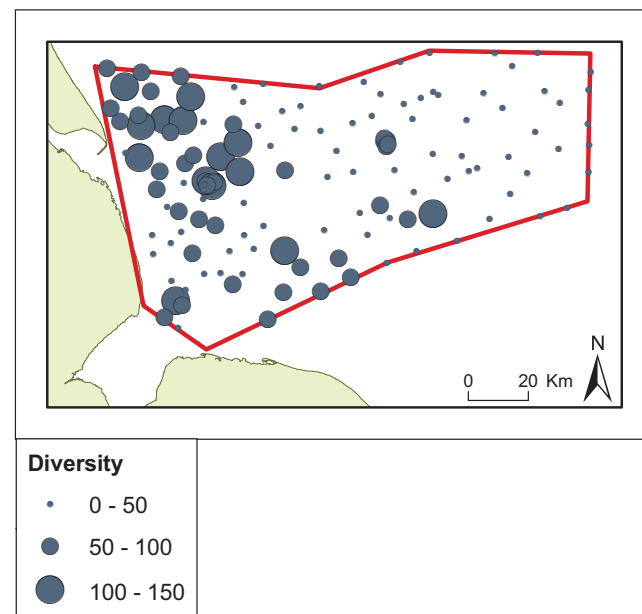


Figure 6.1.3: Total number of species recorded per 0.1 m² Hamon Grab sample taken from within the Humber REC study area.

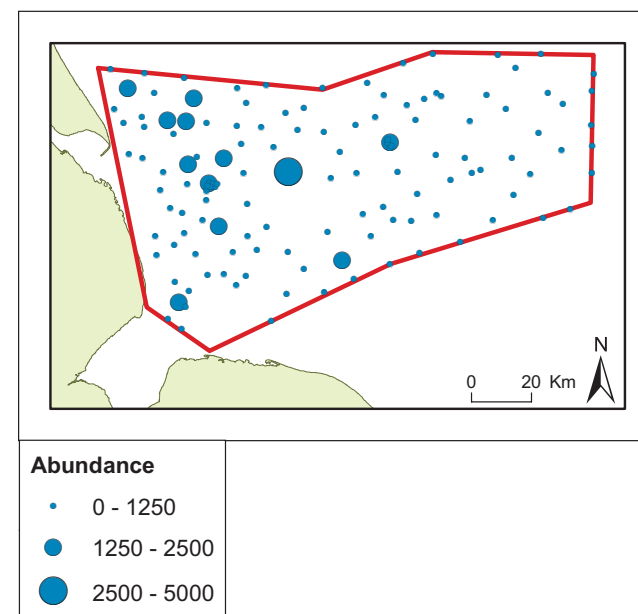


Figure 6.1.4: Total abundance of animals recorded per 0.1 m² Hamon Grab sample taken from within the Humber REC study area.

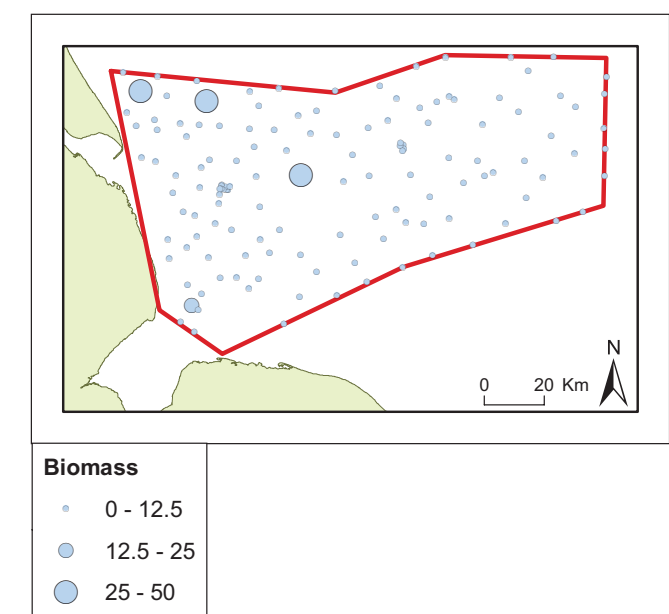


Figure 6.1.5: Total biomass (gAFDW) recorded per 0.1 m² Hamon Grab sample taken from within the Humber REC study area.

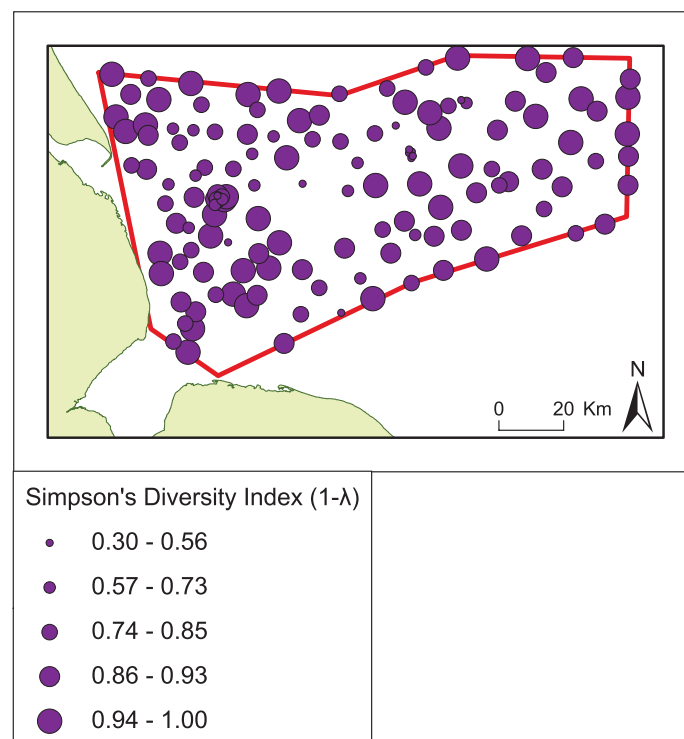


Figure 6.1.6: Simpson's Diversity (1-λ) calculated per 0.1 m² Hamon Grab sample taken from within the Humber REC study area.

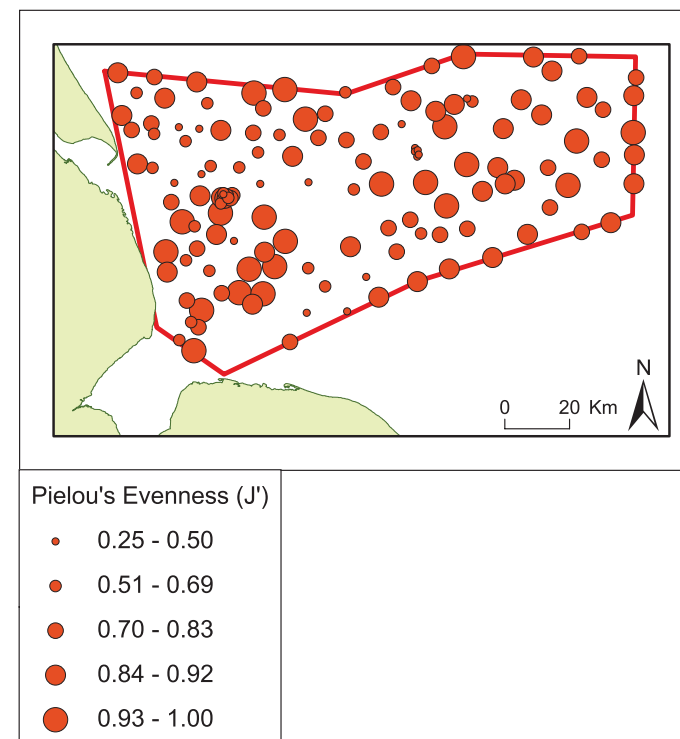


Figure 6.1.7: Pielou's Evenness (J') calculated per 0.1 m² Hamon Grab sample taken from within the Humber REC study area.

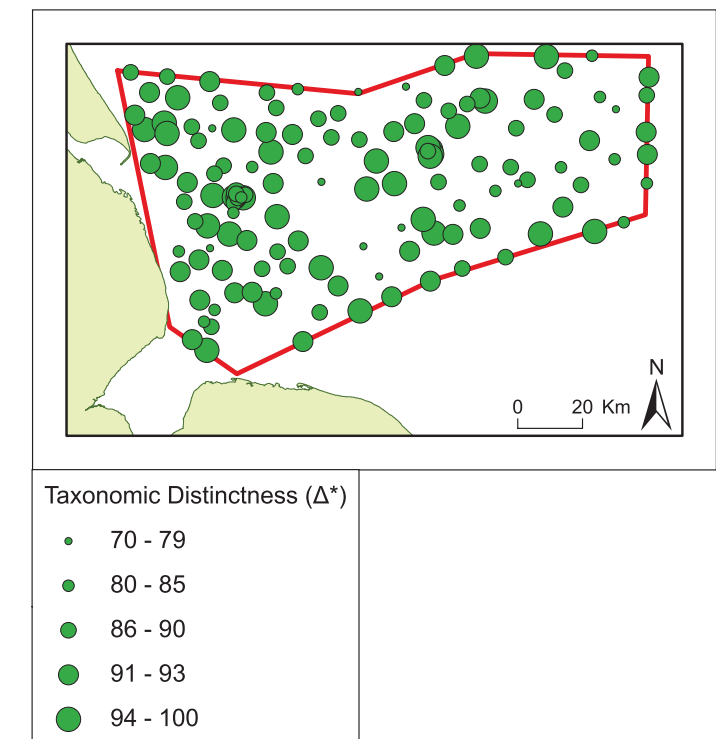


Figure 6.1.8: Taxonomic Distinctness (Δ*) calculated per 0.1 m² Hamon Grab sample taken from within the Humber REC study area.

that all major marine phyla are represented in the eastern half of the study area albeit by fewer species and individuals.

6.1.2 Benthic Macrofaunal Assemblages

Multivariate analysis of the benthic abundance data has been used to identify natural groupings or assemblages which exist across the Humber REC study area utilising statistical routines within the PRIMER v6 software (Clarke & Gorely, 2006; Clarke & Warwick, 2001). The abundance data were fourth root transformed in order to reduce the influence of a few, very abundant species, on the faunal groups derived from this analysis. The resulting data were used to construct a resemblance matrix based on Bray-Curtis similarity which was then used to produce a group average sorting dendrogram. A SIMPROF test was applied to the dendrogram as a means of identifying groups of samples which are not significantly different from one another at the 0.05 % significance level. This test resulted in 29 statistically distinct groups ranging in size from 1–25 samples (Figure 6.1.9).

Since the aim of this research is to provide a broad characterisation of the region a second stage dendrogram was constructed based on the fourth root transformed abundance data, averaged by the 29 statistical groups identified using the SIMPROF test. A SIMPROF test was then applied to the resulting dendrogram as a means of identifying groups which are not significantly different from one another at the 0.05 % significance level (Figure 6.1.10). This method of identifying broad biological groups has not previously been applied but is thought to be somewhat analogous to the second stage multi-dimensional scaling (MDS) ordination which is widely used to visualise broad biological and environmental trends (Clarke & Gorely, 2006). This second stage SIMPROF test reveals 15 higher level groups which for the purpose of this assessment can usefully be considered as benthic assemblages.

A multi-dimensional scaling (MDS) ordination based on the resemblance matrix of fourth root transformed sample abundance data is shown in Figure 6.1.11. The ordination plot has been overlaid with the 15 higher level benthic assemblages identified through the second stage SIMPROF test (Figure 6.1.10). This illustrates that whilst the fauna in the Humber REC study area can be considered as 15 discrete assemblages, there is considerable overlap between them and they are likely to share a number of component taxa.

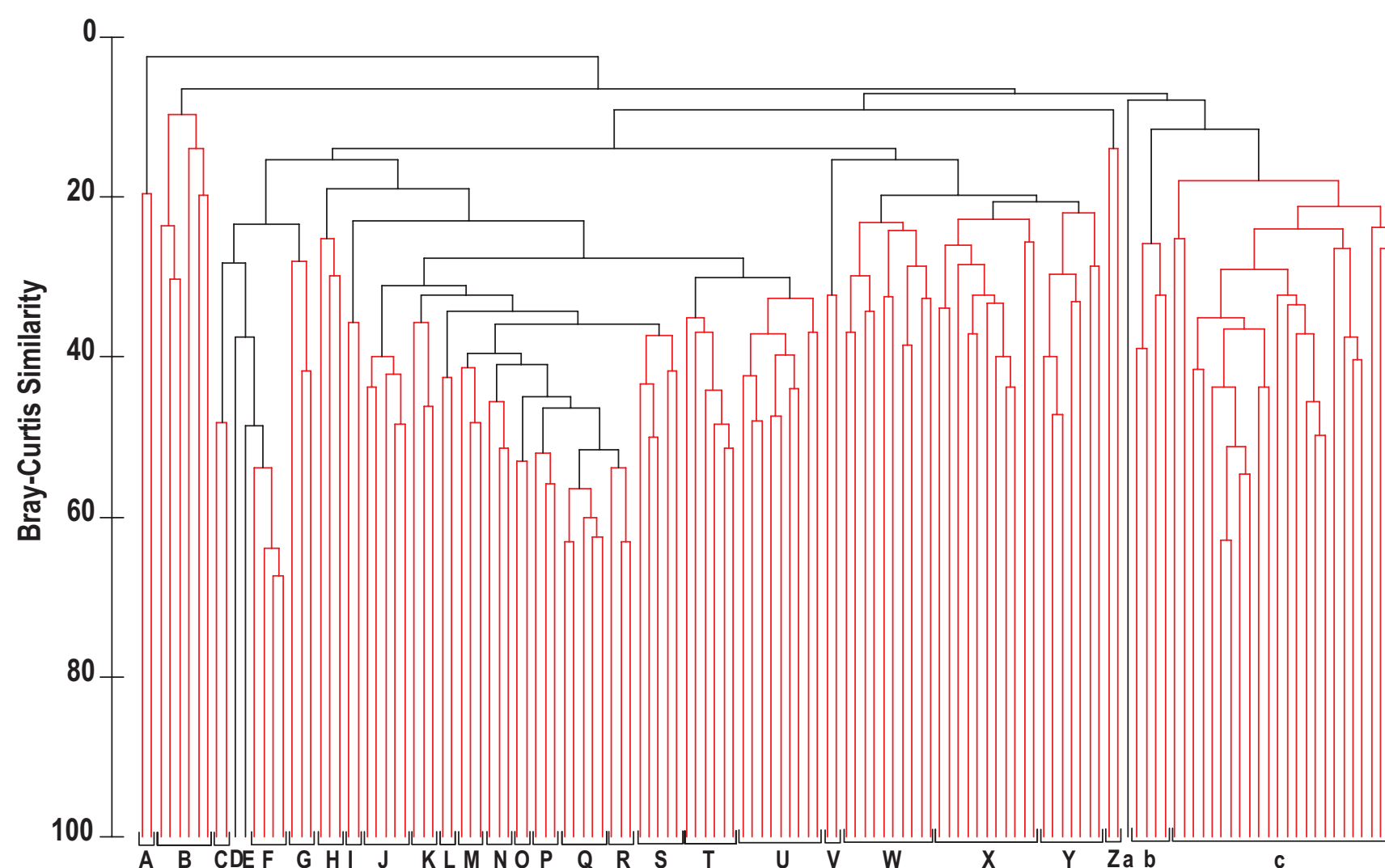


Figure 6.1.9: A group average dendrogram, based on Bray-Curtis similarity of benthic macrofauna (fourth root transformed abundance data) recorded across the Humber REC area. Clusters of stations which are not significantly different from one another ($P < 0.05\%$) are highlighted in red.

The distribution of the faunal assemblages identified through multivariate analysis of the benthic abundance data (Figures 6.1.9–6.1.11) is shown in Figure 6.1.12. The benthic assemblages group well geographically indicating that their composition is driven strongly by the environmental conditions of the study area. The mixed inshore sediments of the study area support a diverse suite of benthic assemblages compared to the sandier sediments to the east which support only a small number of different assemblages. This mirrors the results of the desk based review (Tappin *et al.*

2009) indicating that the broad trends in benthic composition are relatively stable over time.

The dominant assemblage, group 14, which correlates strongly with presence of sand across the area, is dominated by infaunal polychaetes and burrowing amphipods, including *Bathyporeia elegans* a community which is typical of southern North Sea sand deposits (Heip & Craeymeersch, 1995). Although there were many more assemblages occupying the mixed inshore sediment deposits they also correlate well with subtle changes in sediment

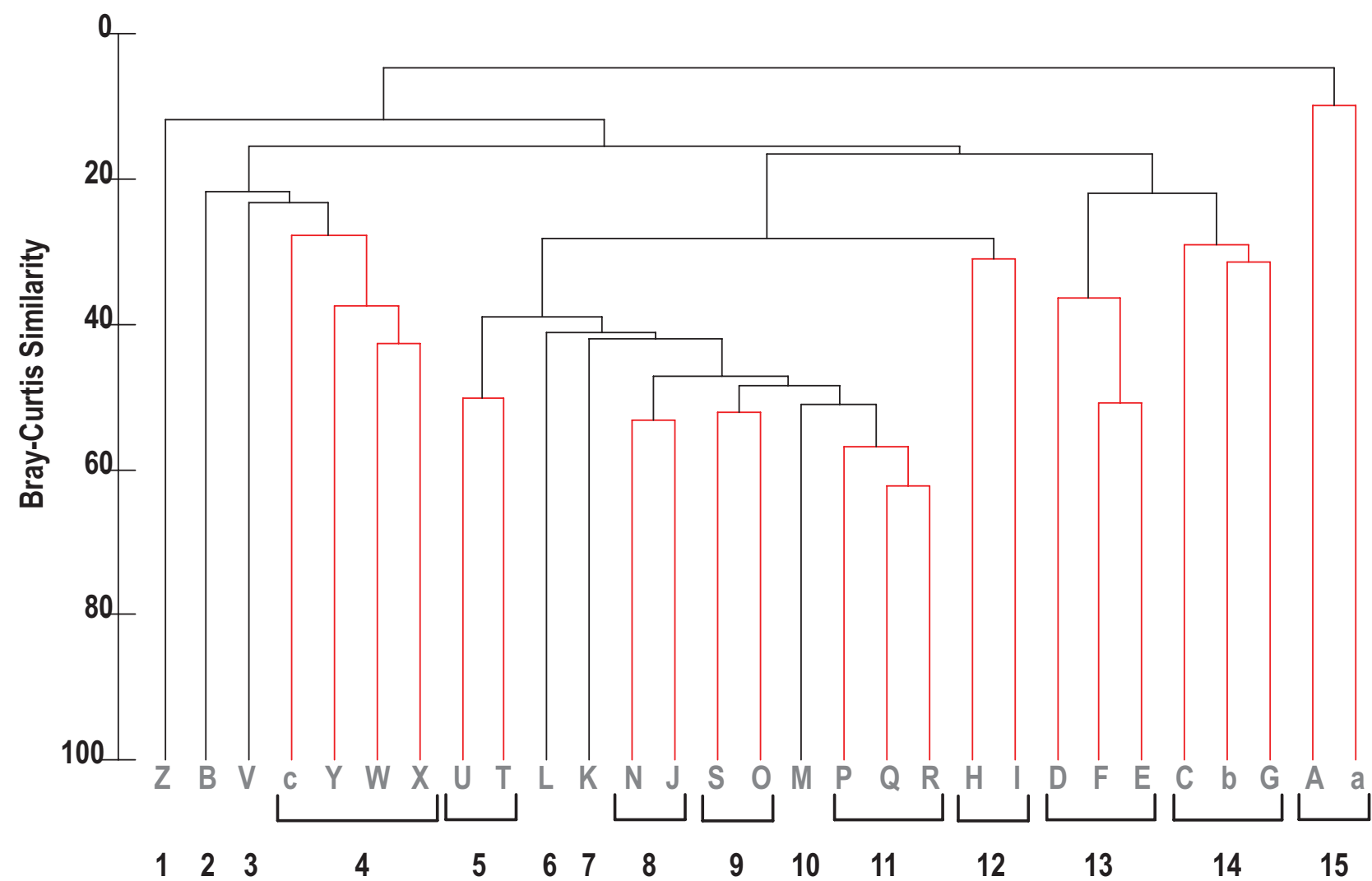


Figure 6.1.10: A group average sorting dendrogram, based on Bray-Curtis similarity of faunal groups identified in Figure 6.1.9 (averaged fourth root transformed abundance data). Clusters of groups which are not significantly different from one another ($P < 0.05\%$) are highlighted in red.

composition. For example assemblage 5 is restricted to muddy sandy gravels whilst assemblage 11 is found solely on sandy gravels. These two assemblages have many species in common and both include a mix of infauna and epifauna. The increase in mud content however, seems to be strongly correlated with a shift from high densities of barnacles to high densities of *Sabellaria spinulosa*. Both are filter feeders but it is likely that morphological differences in their feeding apparatus leads to differences in their tolerance for suspended sediment.

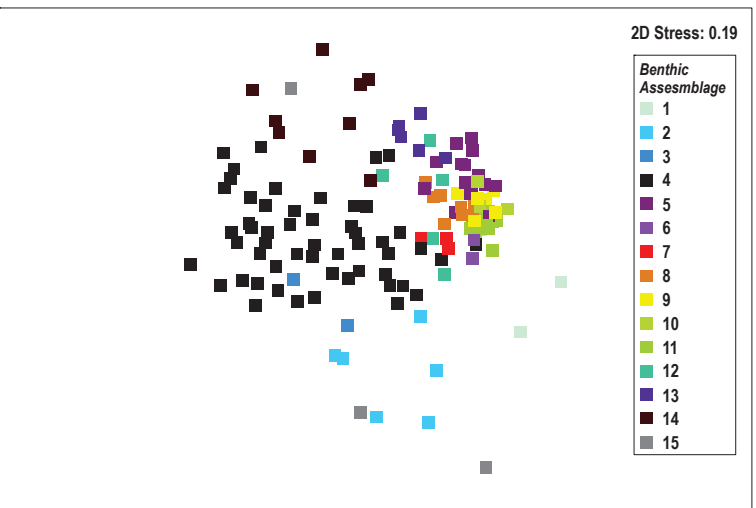
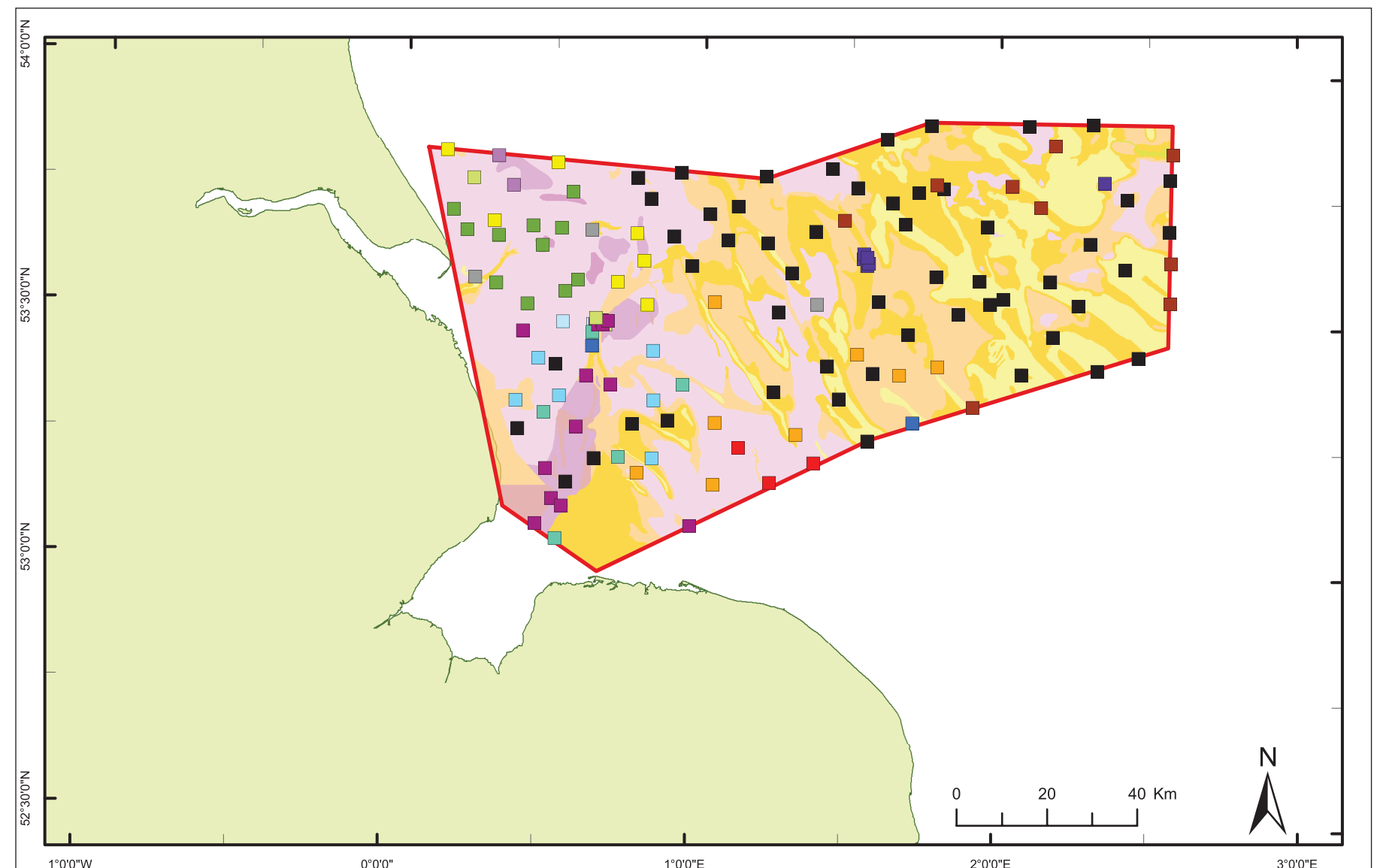
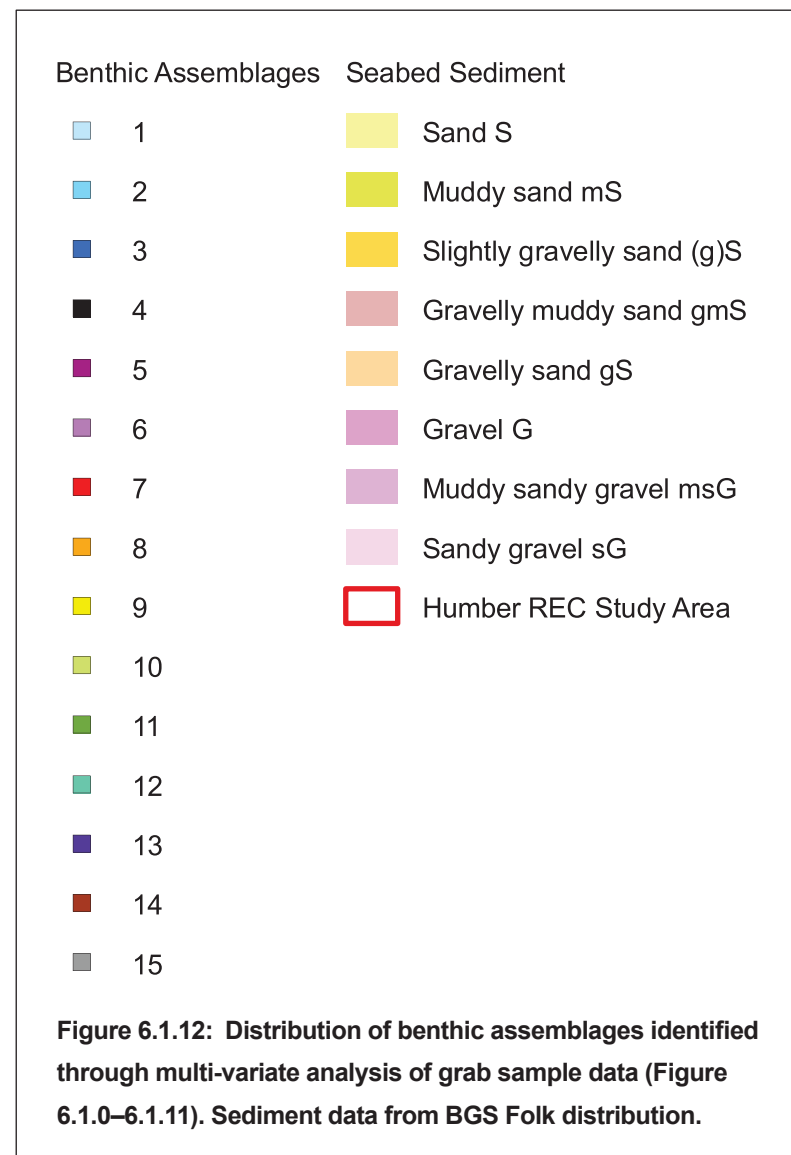


Figure 6.1.11: A multi-dimension scaling (MDS) ordination based on Bray-Curtis similarity illustrating the similarity between the benthos (fourth root transformed abundance data) recorded across the Humber REC area, superimposed with the faunal assemblages identified in Figure 6.1.10.



6.2 Epifauna & Demersal Fish

The diversity of epifauna and demersal fish sampled across the Humber REC study area was relatively low in comparison to other regional assessments (James *et al.* 2007 & 2010; EMU Ltd & Southampton University, 2009) with only 125 taxa observed in 30 trawl samples.

The number of crustacean, mollusc, fish and miscellaneous species, including colonial hydroids and bryozoans were similar across the trawl samples, each accounting for approximately 20% of the total diversity recorded. Very few species of echinoderms and annelids were present in the epibenthic trawl samples. Echinoderms, however, together with crustaceans were numerically dominant, accounting 39% and 40% of the overall abundance respectively. There were fewer fish and miscellaneous taxa, and negligible numbers of molluscs and annelids. This is in part a reflection of the sampling gear used. 2 m beam trawls are designed to sample animals living on or close to the seabed and do not, therefore, adequately sample infaunal animals such as annelids or very mobile animals including fish.

The biomass (g wet weight) of fauna was dominated by echinoderms and miscellaneous taxa (mostly the bryozoans *Alcyonidium diaphanum* and *Flustra foliacea* and the cnidarian *Alcyonium digitatum*), accounting for 36% and 35% of the total respectively (Figure 6.2.1), crustaceans and fish each accounted for just over 10% of total biomass.

The apparent disparity between the abundance and biomass of miscellaneous taxa is an artefact of the way in which colonial animals (which make up the bulk of this group) are recorded. Due to the inherent difficulties of counting colonial animals they are included only in terms of presence (1) or absence (0). Many colonial species, particularly encrusting bryozoans which may be strongly attached to the surface of the substrata, are difficult to weigh and hence may also be underrepresented in the biomass data.

Figure 6.2.2 shows the ten most abundant species recorded in trawl samples taken across the Humber REC study area. The brittle star *Ophiothrix fragilis* was the most abundant species with over 5000 individuals observed in just 30 trawl samples. *O. fragilis* is gregarious in nature, often forming dense beds, making high

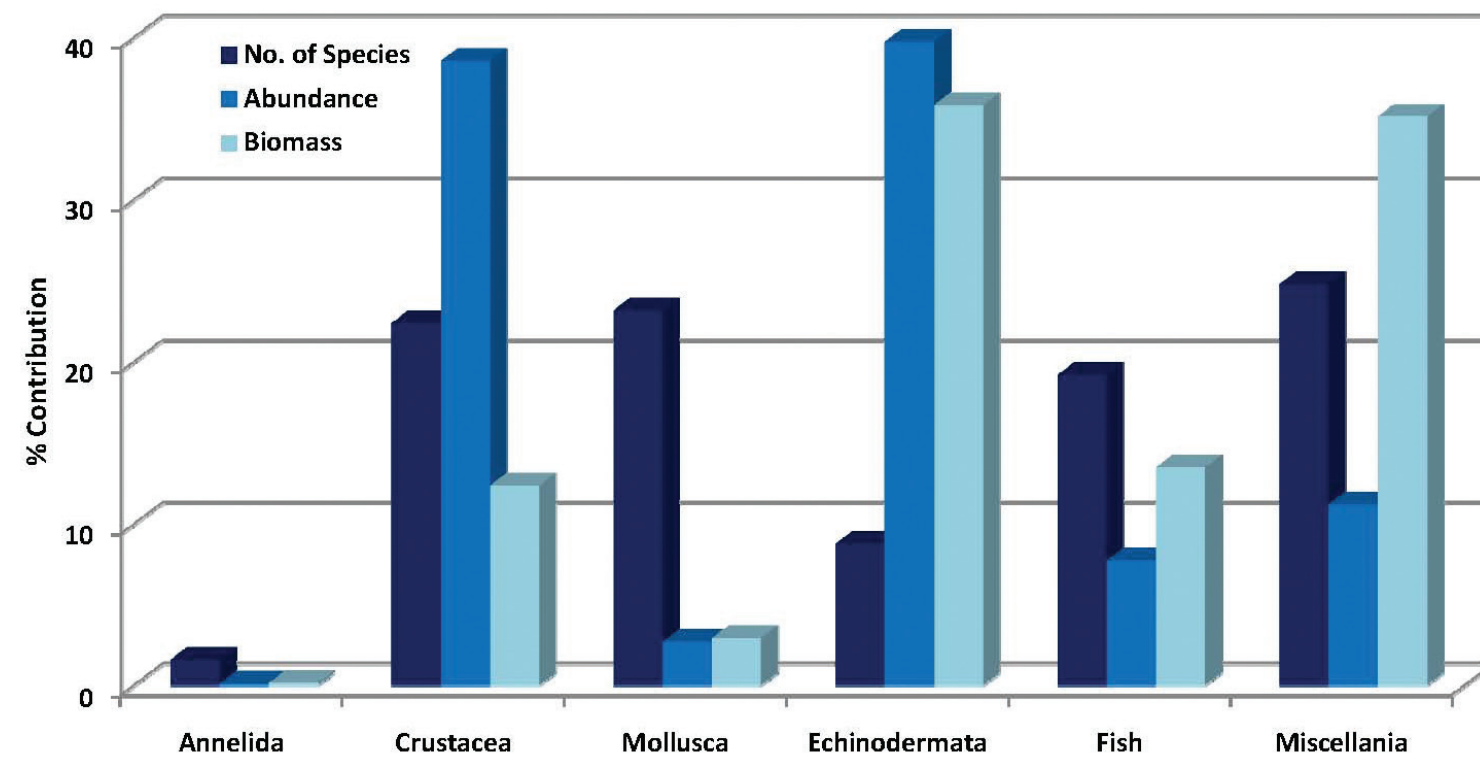


Figure 6.2.1: Relative contributions of major phyla to the number of benthic species (diversity), abundance and biomass (g Wet Weight) recorded from 2 m Beam trawl samples taken across the Humber REC area.

abundances common under favourable environmental conditions (Morgan and Jangoux 2004 & 2005). Like other brittle stars, *O. fragilis* is a suspension-feeding species found in hydrodynamically active areas rich in suspended sediments (Morgan and Jangoux 2004). This species has also been reported to show a preference for coarse sediments (Lefebvre, Ellien *et al.* 2003), making the inshore half of the Humber REC study area an ideal habitat for *O. fragilis*. The brittlestar *Ophiura albida* was also present in fairly high abundance. These brittle stars do not aggregate into beds in the same way as *O. fragilis* but are often recorded in high densities. This species is found sublittorally, on a variety of soft substrata but mainly fine muddy sands.

The second most abundant species in the Humber REC trawl samples was the prawn *Pandalus montagui* which is most commonly found in association with sublittoral mixed or coarse sediments, reflecting the physical heterogeneity of this area. This species is also thought to have a strong association with

Sabellaria spinulosa (Warren & Sheldon, 1967), the second most abundant species recorded from the benthos (Figure 6.1.2). *Pandalina brevirostris*, another prawn typical of coarse sediment habitats was also present in fairly high abundance in the Humber REC study area.

Other abundant species include the common starfish *Asterias rubens*, the shrimp *Crangon allmani*, and the ascidian *Dendrodoa grossularia*. The fish *Buglossidium luteum* (the solenette) and the weaver fish *Echiichthys vipera* were also present in the survey area in fairly high numbers.

6.2.1 Spatial Patterns in Epibenthic Composition and Diversity

The number of species, abundance and biomass (g Wet weight) of epifauna and demersal fish extracted from each of the trawl samples are presented in Figures 6.2.3–6.2.5. The number of species recorded in the trawl samples shows little variation across

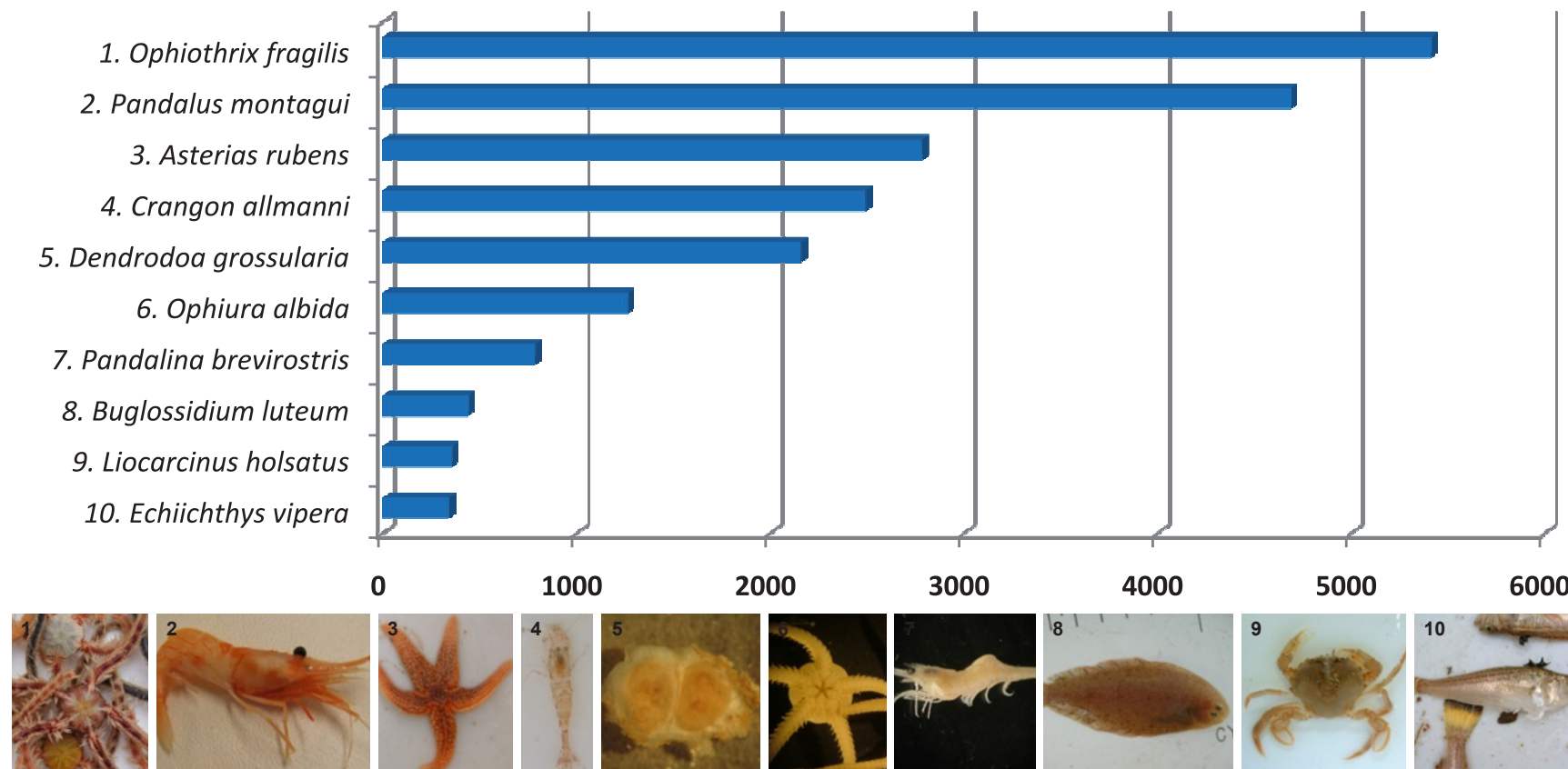


Figure 6.2.2: Total abundance across 30 samples of the ten most abundant species recorded in 2 m beam trawl samples taken across the Humber REC area. Photographic images of the top ten benthic species are also shown.

the study area averaging at 26 species per trawl. The abundance and biomass show much greater variation with significantly higher values of each at Station 86 taken from the Sole Pit, a deep tunnel valley (~80 m) in the eastern sector of the Humber REC study area. The high abundance of fauna recorded at station 86 (12 005 individuals) was mostly accounted for by the brittlestars *Ophiothrix fragilis* and *Ophiura albida* although the common starfish, *Asterias rubens* the prawns, *Pandalus montagui* and *Pandalina brevirostris* and the shrimp *Crangon allmanni* were also present in high abundances. This indicates that this area is very productive in terms of epifaunal species.

There is no real pattern or gradient in the biomass or abundance across the study area and although there is some correspondence between the two there are many stations where there is low abundance and high biomass, or high abundance and low

biomass. This is a reflection of the variation that exists in the body size of epifaunal and demersal fish species.

To further investigate patterns of biological diversity across the study area the same suite of standard diversity measures applied to the benthic data were calculated for each of the trawl samples. These results are represented in Figures 6.2.6–6.2.8. There is a relatively high level of variation in the Simpson's Diversity Index ($1-\lambda$) and Pielou's Evenness (J') across the area (Figure 6.2.6 & 6.2.7) indicating that the epifaunal and demersal fish assemblages are very variable in their diversity and dominance. Taxonomic Distinctness (Δ^* , Figure 6.2.8) of the epifauna was between 70 and 97 across much of the Humber REC study area, indicating that this area supports a moderate to high diversity of epibenthic fauna, although this was also very variable. There was no obvious geographical pattern observed in any of the measures of epifaunal

diversity with the exception of very high abundance and biomass associated with the Sole Pit.

6.2.2 Epibenthic Assemblages

Multivariate analysis of the trawl abundance data has been used to identify natural groupings or assemblages which exist across the Humber REC study area utilising statistical routines within the PRIMER v6 software (Clarke & Gorely, 2006; Clarke & Warwick, 2001). The abundance data were fourth root transformed in order to reduce the influence of a few, very abundant species, on the faunal groups derived from this analysis. The resulting data were used to construct a resemblance matrix based on Bray-Curtis similarity which was then used to produce a group average sorting dendrogram. A SIMPROF test was applied to the dendrogram as a means of identifying groups of samples which are not significantly different from one another at the 0.05% significance level. This test resulted in 6 statistically distinct groups ranging in size from 1 to 9 samples (Figure 6.2.9).

The corresponding multi-dimensional scaling (MDS) ordination is shown in Figure 6.2.10. This shows that in contrast to the benthic assemblages, there is little overlap between the epibenthic assemblages and they form six quite discrete groups. The distribution of the epibenthic groups identified in Figures 6.2.9 and 6.2.10 is illustrated in Figure 6.2.11. The epifaunal assemblages group well geographically indicating that their composition is driven strongly by the environmental conditions in the study area.

Trawl 40 did not group with any of the other samples as the fauna was significantly different to that recorded at all other sites ($P < 0.05\%$). Close inspection of the raw data (Appendix E) shows that the trawl sample 40 was characterised by a very sparse fauna. The organisms that were present in this sample include single individuals of the harbour crab *Liocarcinus depurator*, the hermit crab *Pagurus bernhardus*, the common starfish *Asterias rubens* and the bivalve *Circomphalus casina* and a very low biomass of the bryozoan *Flustra foliacea* and hydroid *Sertularia* spp.

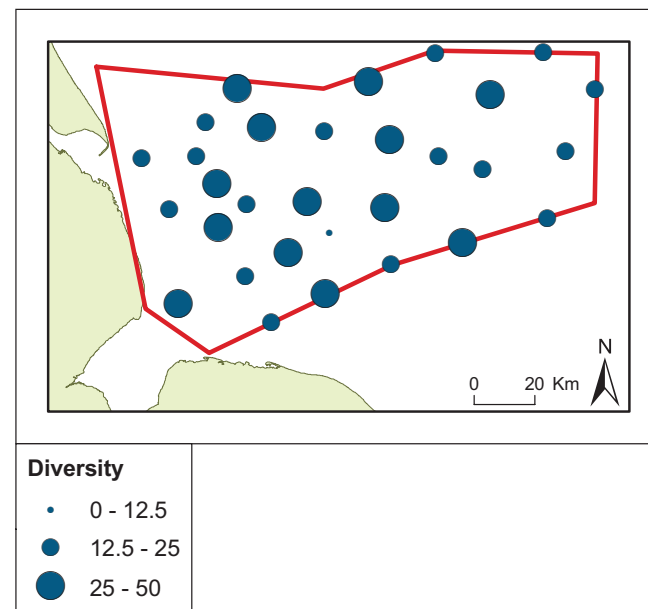


Figure 6.2.3: Total number of species recorded per 2 m beam trawl sample taken within the Humber REC area.

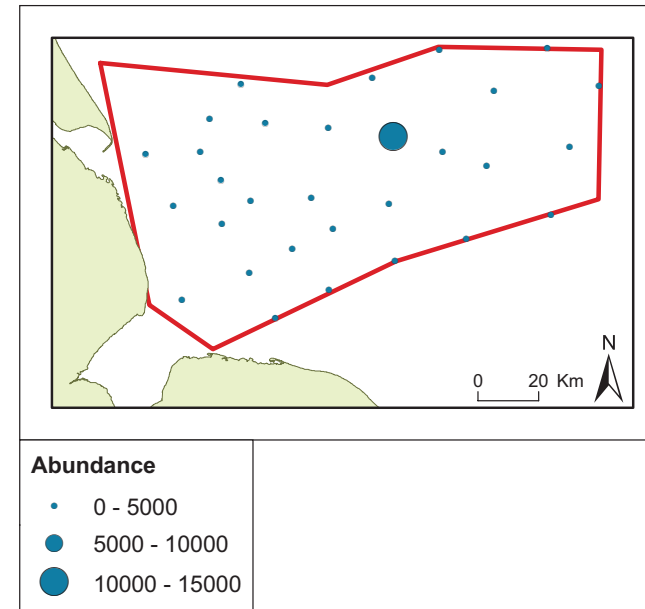


Figure 6.2.4: Total abundance of animals recorded per 2 m beam trawl sample taken within the Humber REC area.

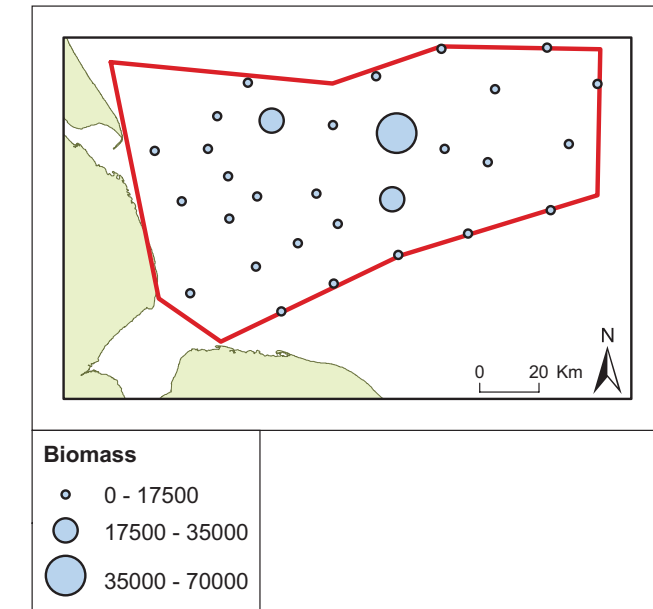


Figure 6.2.5: Total biomass (gAFDW) recorded per 2 m beam trawl sample taken within the Humber REC area.

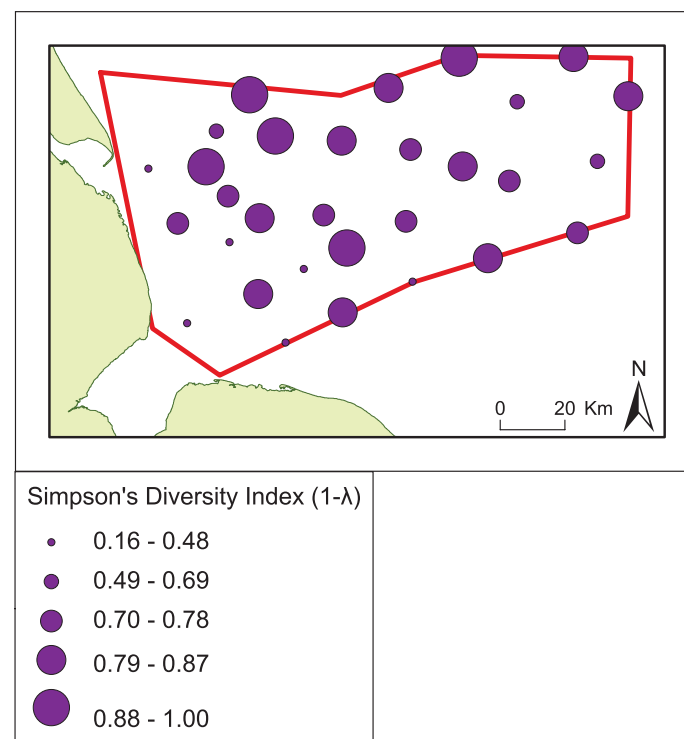


Figure 6.2.6: Simpson's Diversity (1-λ) calculated per 2 m beam trawl sample taken within the Humber REC area.

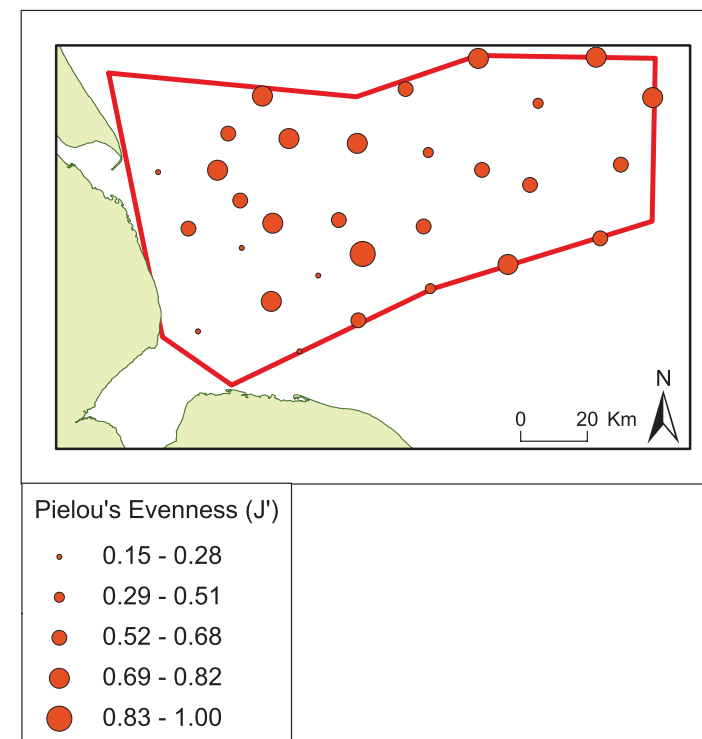


Figure 6.2.7: Pielou's Evenness (J') calculated per 2 m beam trawl sample taken within the Humber REC area.

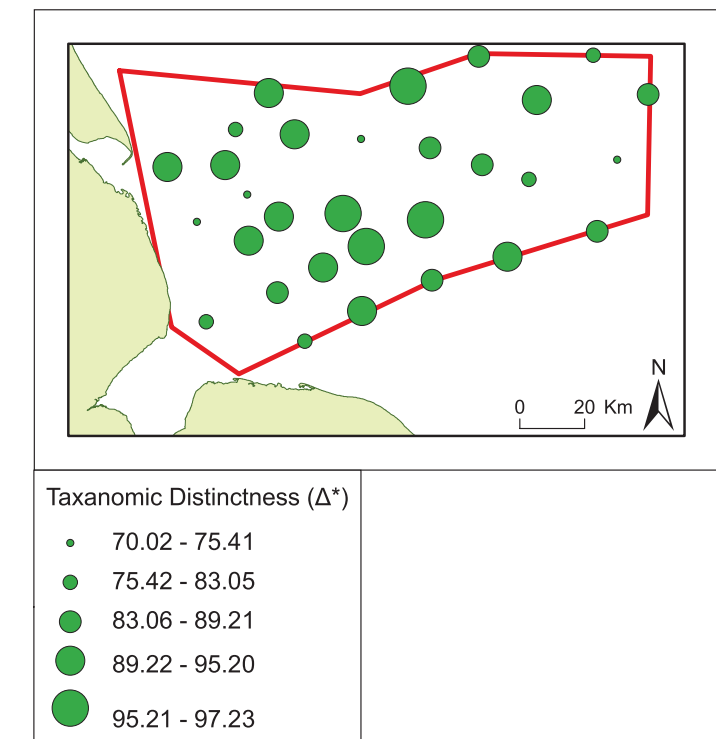


Figure 6.2.8: Taxonomic Distinctness (Δ*) calculated per 2 m beam trawl sample taken within the Humber REC area.

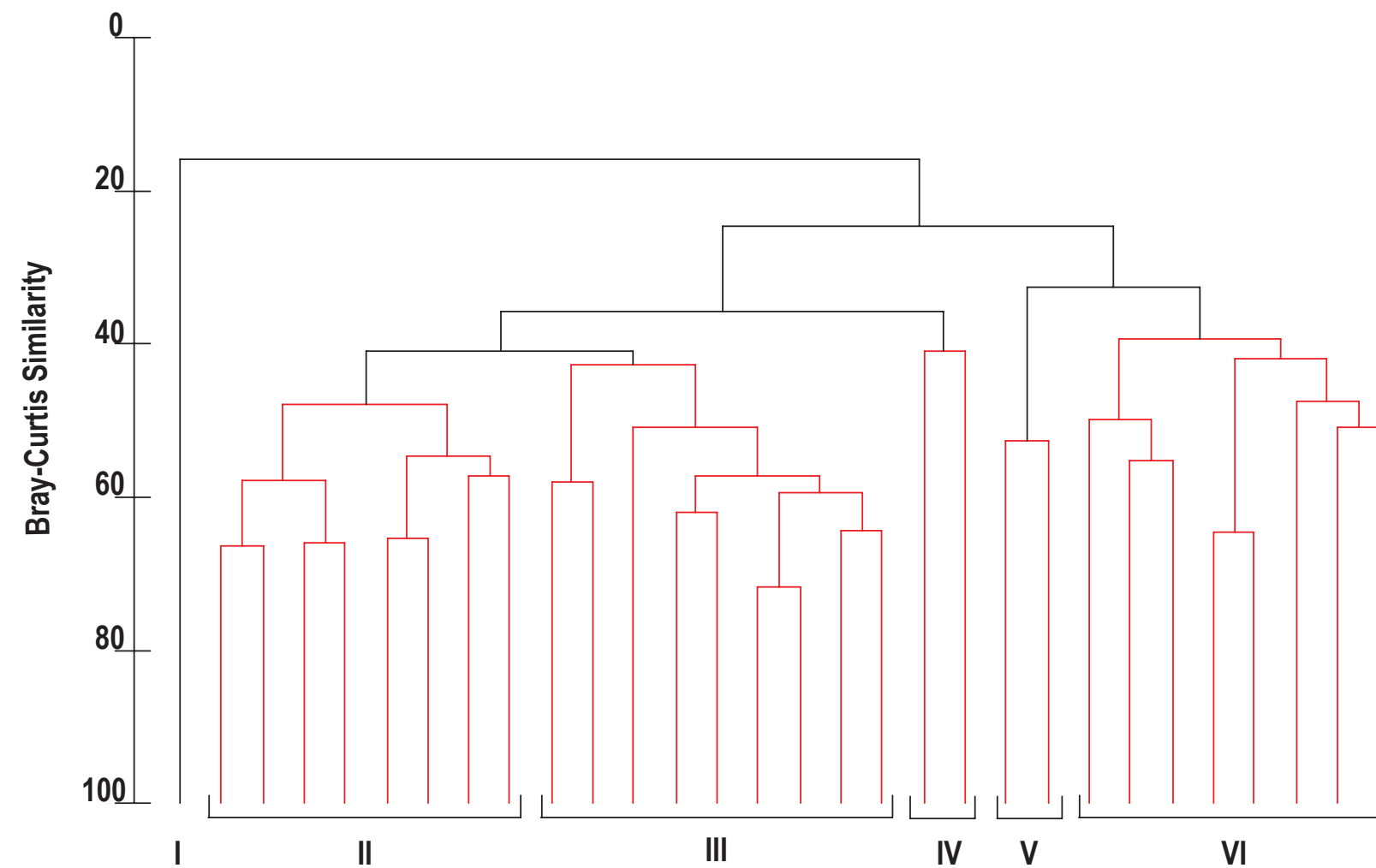


Figure 6.2.9: A group average sorting dendrogram, based on Bray-Curtis similarity of the epibenthos (fourth root transformed trawl abundance data) recorded across the Humber REC area. Clusters of samples which are not significantly different from one another ($P < 0.05$ %) are highlighted in red.

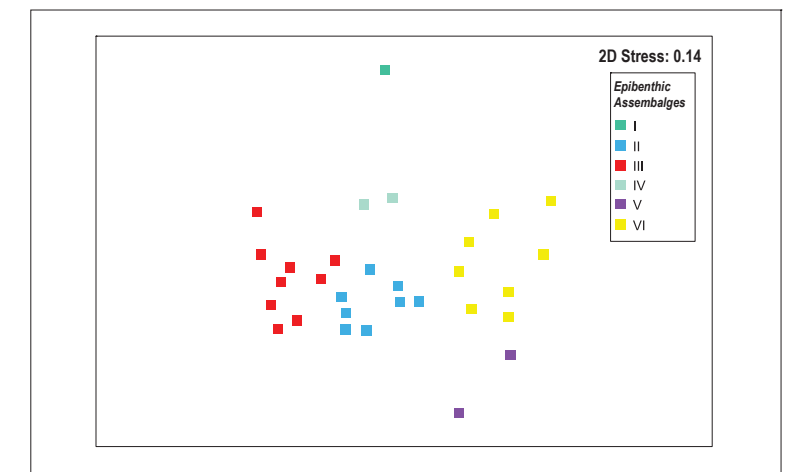


Figure 6.2.10: A multi-dimensional scaling (MDS) ordination based on Bray-Curtis similarity illustrating the similarity between the epibenthos (fourth root transformed trawl abundance data) recorded across the Humber REC area, superimposed with the epibenthic assemblages identified in Figure 6.2.9.

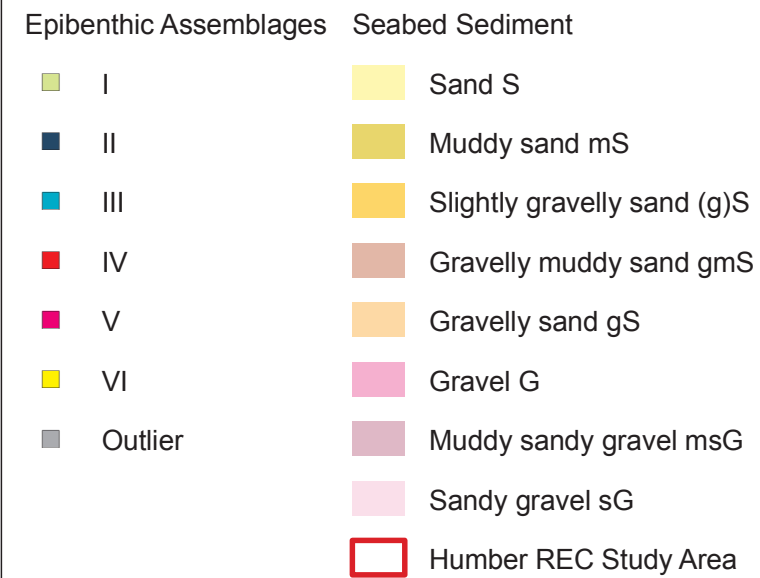
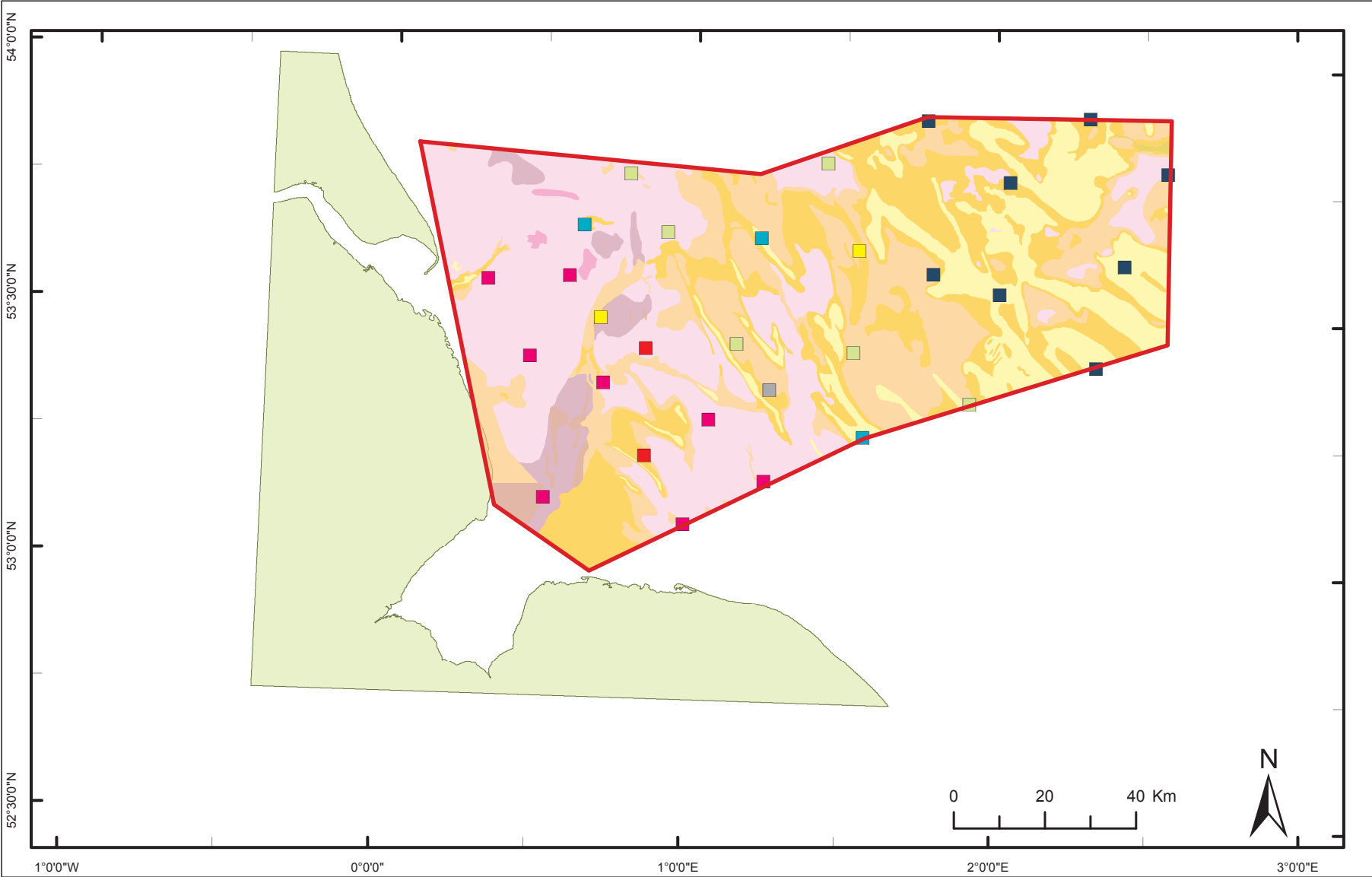


Figure 6.2.11: Distribution of epibenthic assemblages identified through mulit-variate analysis of trawl sample data (Figure 6.2.9 & 6.2.10). Sediment data from BGS Folk distribution.



6.3 Sea Bed Habitats

Video footage and digital still images were collected across the Humber REC study area and these were examined in order to identify the seabed habitats present and also to identify key epifaunal communities (For full details data is available from www.marinealsf.org.uk). Viewing a large area of the seafloor at each sampling station also provides information on small scale variability in the habitats as well as information about the way in which species are associated, which is not available from grab and trawl sampling alone.

Figure 6.3.1 shows a selection of seabed images collected across the Humber REC study area, illustrating the variation which exists amongst the four broad seabed habitats identified. Almost half of the area was observed to be sand whilst the other half was observed to be mixed sediments ranging from predominantly sand habitats with occasional cobbles or outcropping rock, to very coarse cobble dominated sediments (Figure 6.3.2). Exposed boulder clay was observed at just four stations (Stations 73, 74, 90 and 111).

The distribution of seabed habitats across the Humber REC study area is illustrated in Figure 6.3.3. Also shown are the stations at which aggregations of the Ross worm, *Sabellaria spinulosa* and the brittle star *Ophiothrix fragilis* were observed in the video and stills images. The seabed habitats described from the underwater video and digital still images correlate very well with the sediment distribution described in Figure 4.2.3 (Refer to BGS Sediment Map), adding further verification to this interpretation. Aggregations of *Sabellaria spinulosa* and *Ophiothrix fragilis* were found almost exclusively in association with the Silver Pit and were notably absent from the east of the region. *Sabellaria spinulosa* reef has previously been noted in environmental impact assessments of aggregate extraction areas adjacent to the Silver Pit indicating that this may be a relatively persistent feature (Emu, 2005, MES, 2003, MES, 2009).

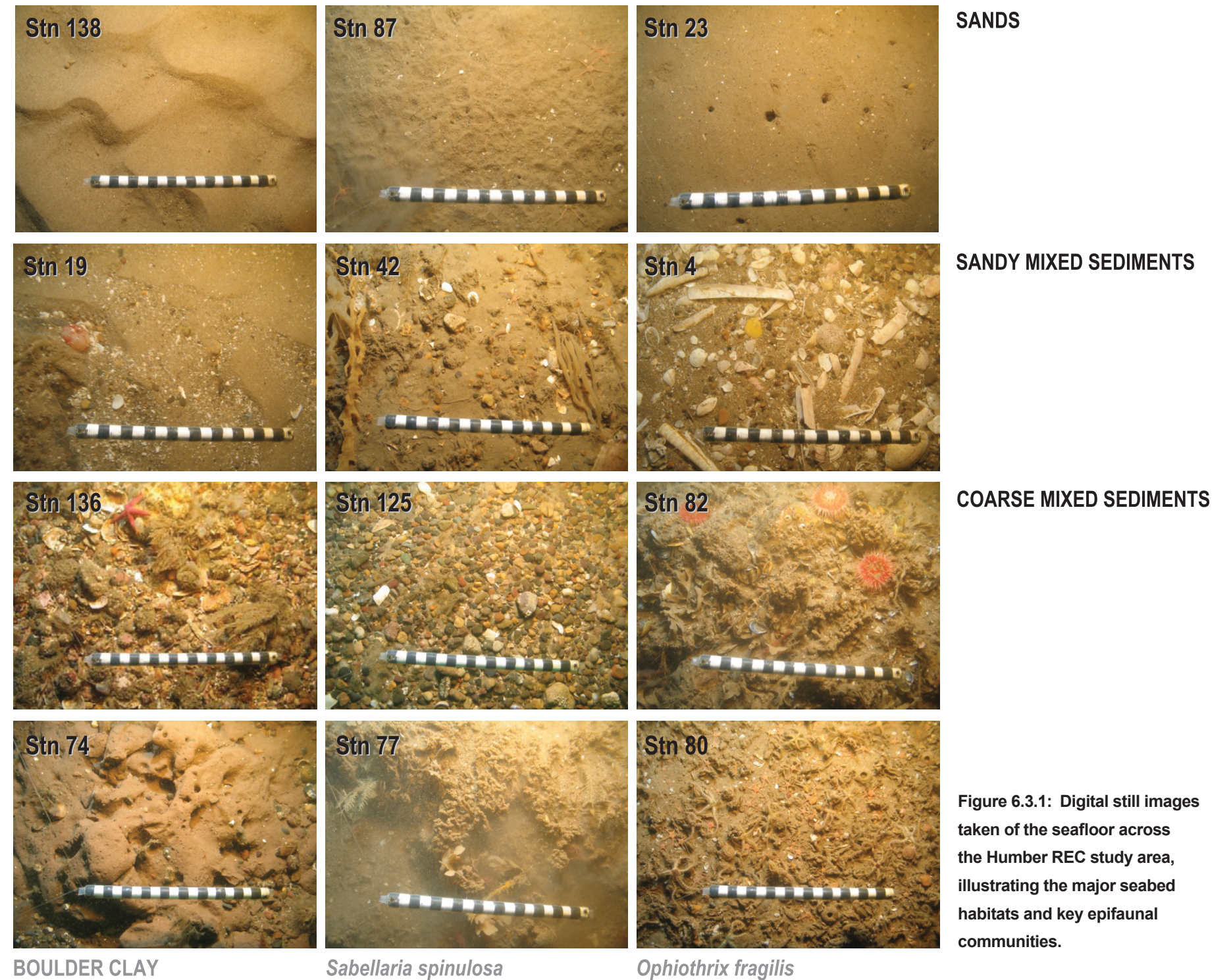
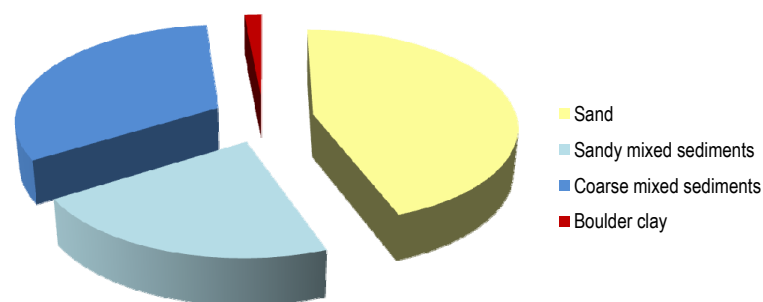


Figure 6.3.1: Digital still images taken of the seafloor across the Humber REC study area, illustrating the major seabed habitats and key epifaunal communities.

Figure 6.3.2: Proportion of seabed habitats observed during analysis of the 133 underwater video and stills images.

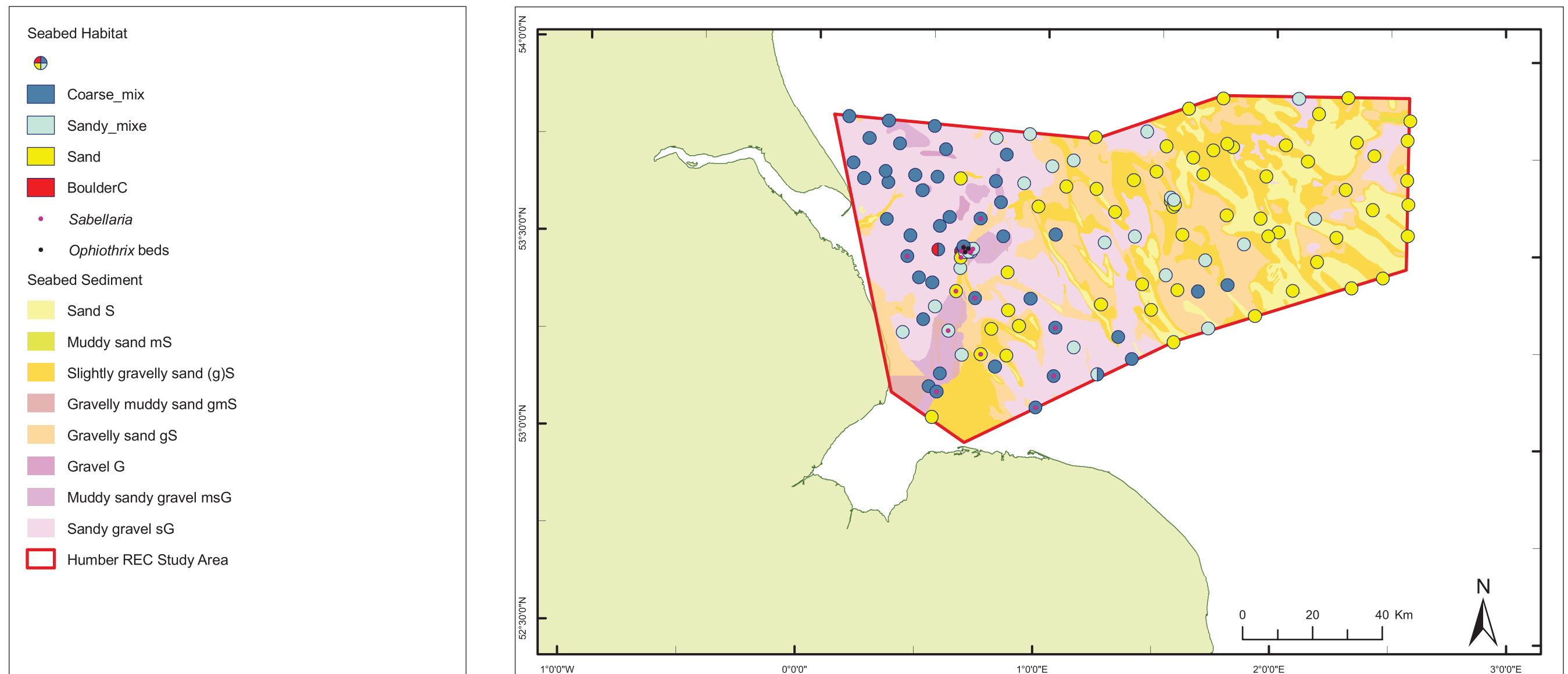


Figure 6.3.3: Chart showing the distribution of seabed habitats observed from underwater video and still images taken from across the Humber REC study area. Also shown are the stations where *Sabellaria spinulosa* and *Ophiothrix fragilis* aggregations were observed. Sediment data from BGS Folk distribution.

6.4 Functional Biological Communities

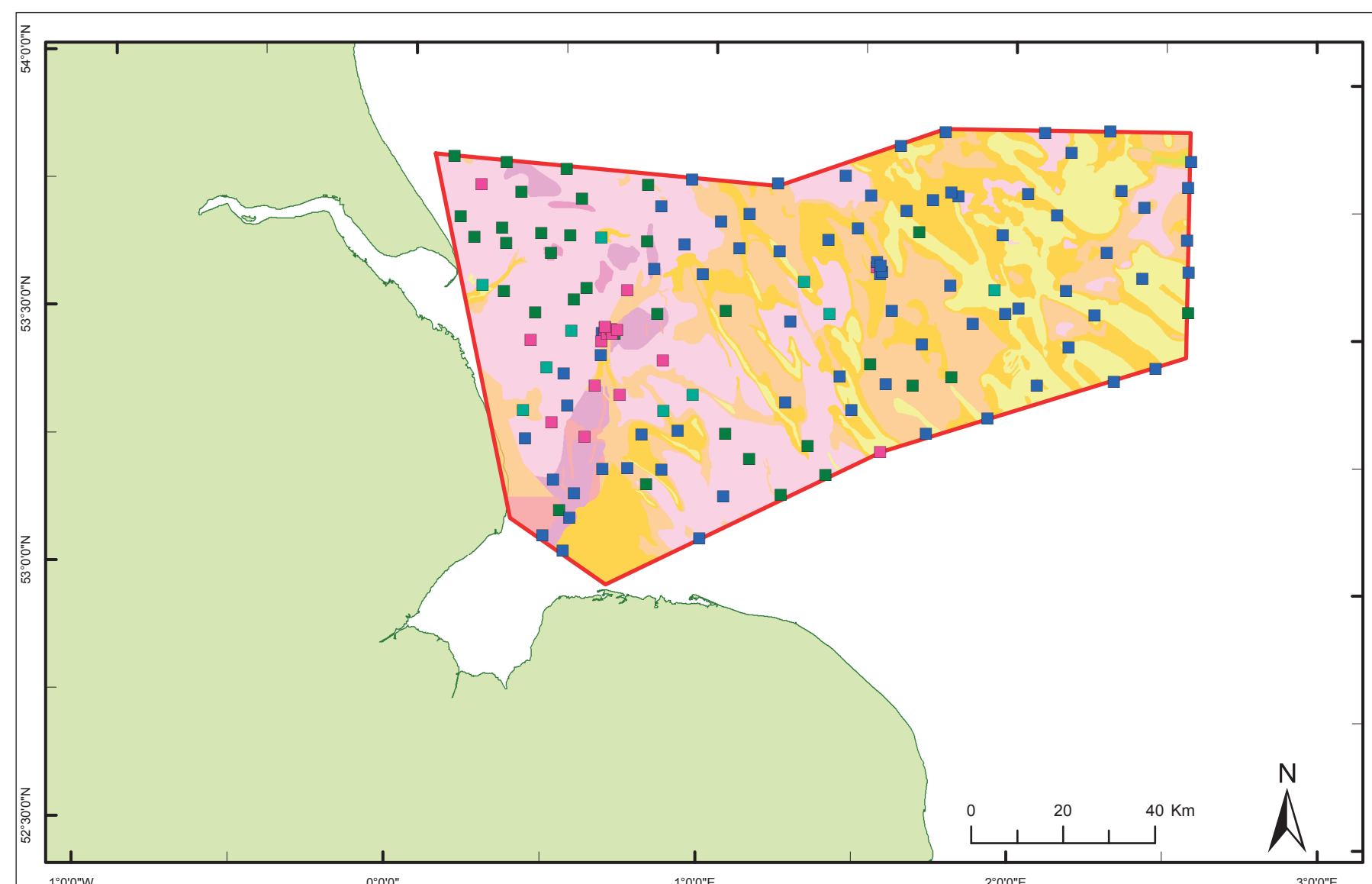
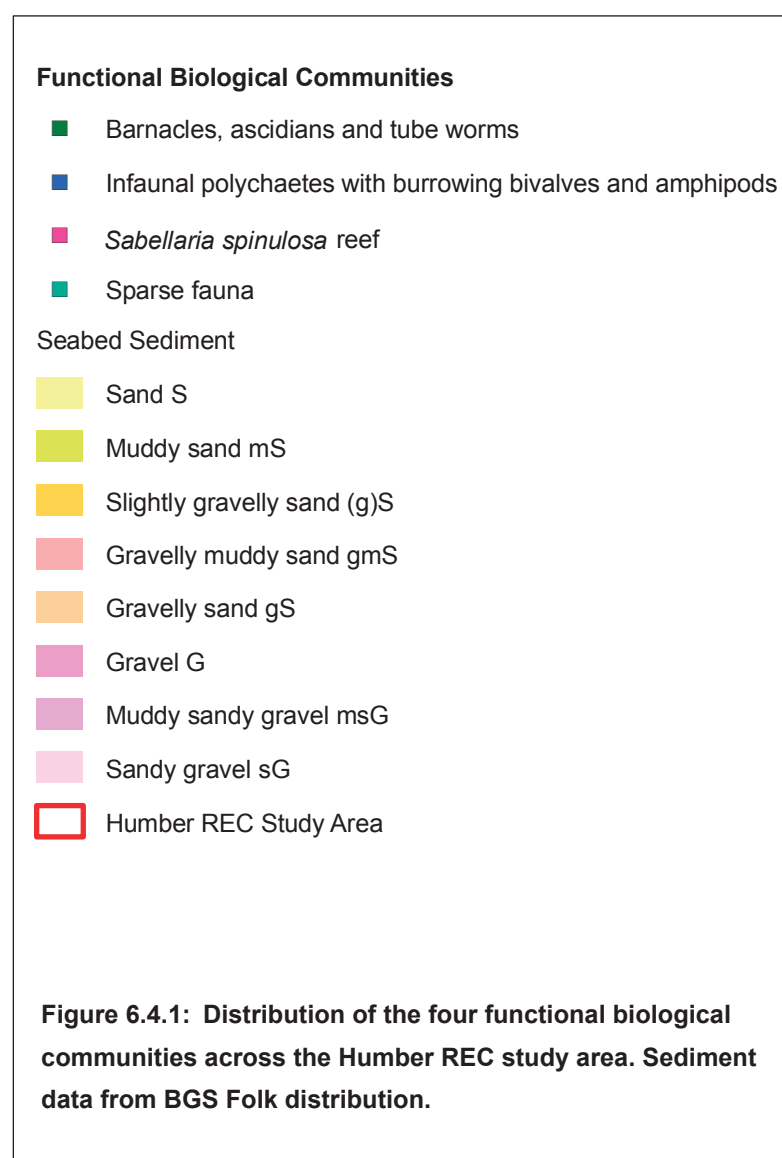
Although the distribution of animals in the marine environment is influenced to some extent by the environmental conditions there is also a large element of chance involved. The vast majority of marine animals have a planktonic stage in their development which leads to a patchy distribution where the precise composition of an assemblage is dependent largely on stochastic events such as which species are in their planktonic stage when a marine habitat becomes available (either through disturbance or natural mortalities of individuals). It is therefore useful to consider 'higher level' functional biological communities in the context of mapping

at this broadscale since there is every likelihood that the precise species composition will vary spatially and temporally.

The previous report Sections 6.1–6.3 describe the benthic assemblages, epibenthic assemblages and seabed habitats of the Humber REC study area as derived from analyses carried out on the data collected. In order to integrate these assessments the data available from each sampling station was re-examined and expert judgement was used to assign each station to a broad functional biological community based on the functional role of animals present rather than the specific species. Four broad level functional communities were identified (Figure 6.4.1) as follows;

1. Barnacles, ascidians and tubicolous polychaetes
2. Infaunal polychaetes with burrowing bivalves and amphipods
3. *Sabellaria spinulosa* reef
4. Sparse fauna

The range of fauna making up these functional biological communities and the environmental conditions under which they are found is described in the following pages.



6.4.1 Functional Biological Communities

Functional Biological Community 1 — Barnacles, Ascidians and Tube Worms

This community is found in areas of the Humber REC that are characterised by coarse or mixed sediment types (Figures 6.4.2 and 6.4.3) which provide attachment for a number of epifaunal species (Figures 6.4.4 and 6.4.5). It is found across several EUNIS Level 4 habitats including deep layers of coarse, mixed and sandy sediments and thin layers of similar sediments overlying bedrock (Figure 6.4.3). Similar assemblages dominated by barnacles and ascidians, which often have high recruitment, have been observed in other areas of the southern North Sea (e.g. see Kenny & Rees, 1994; 1996).

The patchy distribution of this community will be largely determined by random recruitment of larvae to gravel and other coarse substrates. There are, however, several species including barnacles that will settle preferentially where adults are already present and in these areas very high abundance of a single species may be observed.

Balanus crenatus is the barnacle species typically found in this functional community across the Humber REC study area (Figure 6.4.5). This species is generally found in high abundance with an average of over 300 individuals per grab, although there is considerable variability ranging from zero to over 2000 individuals per grab. Another barnacle, *Verruca stroemi*, is also present in this community, albeit in much lower abundance. There are many areas where the two species co-exist. Small sea squirts, particularly *Dendrodoa grossularia*, and the tube worm *Pomatoceros* spp. are also variable in number but are often found in high abundance. Where sand is present the tube building polychaete *Sabellaria spinulosa* may also be present. A number of different bivalve, amphipod and infaunal polychaete species are also likely to occur in this functional community. The alien American slipper limpet *Crepidula fornicata* is also observed in this group, although abundances in the Humber REC are considerably lower than other areas such as the south coast (James *et al.* 2010). The presence and abundance of these other taxa probably reflects the nature of the sediment, particularly the proportion of sand, and the natural spatial variability commonly observed in marine invertebrate assemblages.

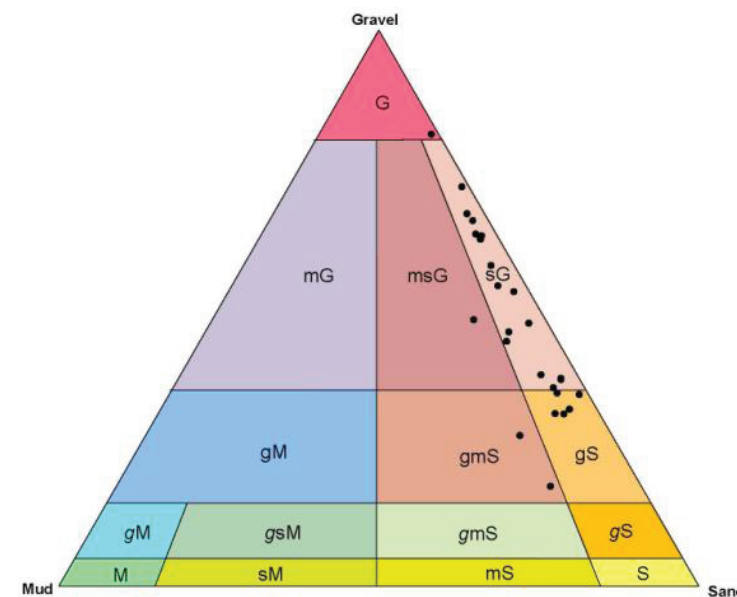


Figure 6.4.2: Folk sediment triangle for Functional Biological Community 1 with seabed image of Station 12 showing typical habitat type.



Figure 6.4.5: Key fauna for Functional Biological Community 1: The barnacle *Balanus crenatus*, ascidians and the tube worm *Pomatoceros* spp.

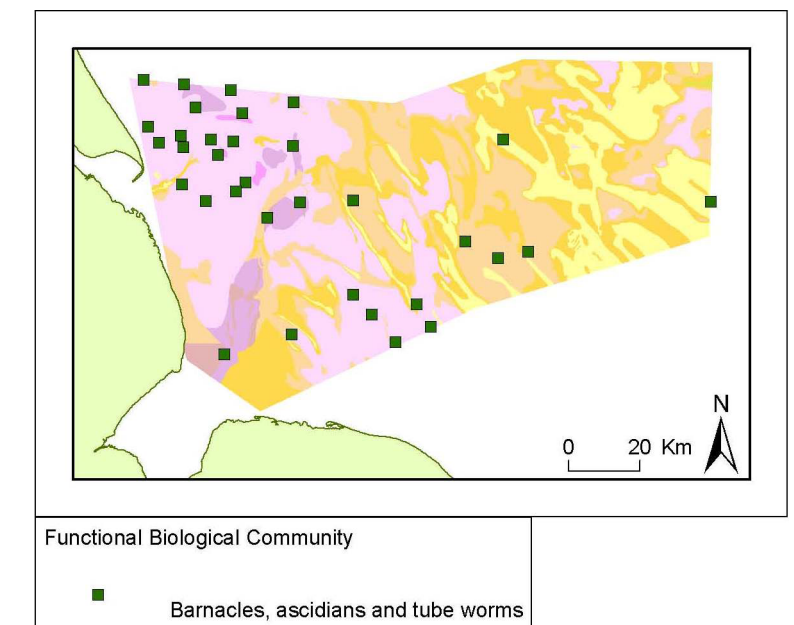


Figure 6.4.3: Distribution of Functional Biological Community 1 across the Humber REC study area.

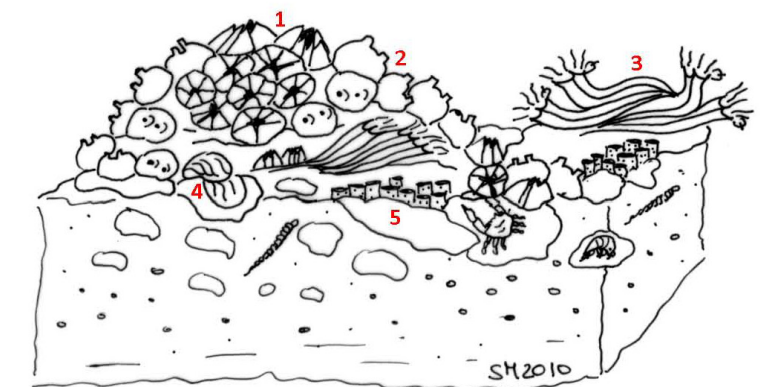


Figure 6.4.4: Diagram of Functional Biological Community 1: Species illustrated include 1. *Balanus crenatus*, 2. *Dendrodoa grossularia*, 3. *Pomatoceros* spp., 4. *Crepidula fornicata*, 5. *Sabellaria spinulosa*.

Functional Biological Community 2 — Infaunal Polychaetes with Burrowing Bivalves and Amphipods

Infaunal invertebrates dominate this functional community that is found in habitats with a minimum sand component of 30% that may be overlaid by a veneer of gravels or shell fragments (Figure 6.4.6). It is most dominant in the deeper eastern section of the Humber REC study area (Figure 6.4.7).

The polychaetes *Ophelia borealis*, *Polycirrus* spp. and *Spiophanes* are particularly widespread, as are nemertean worms (Figures 6.4.8 and 6.4.9). *O. borealis* is the most abundant polychaete in this community (Figure 6.4.9). Burrowing bivalves are also common, although species distributions are highly patchy in nature and the presence of a particular species probably reflects sediment preferences to some degree. For example, the bivalve *Abra alba* (Figure 6.4.9) is found in very high abundance, up to over 900 individuals per grab, in those habitats that have a muddy sediment component. The bivalves *Mysella bidentata* and *Goodallia triangularis* also occur in this functional community. Burrowing amphipods, in particular *Urothoe elegans*, and *Bathyporeia* and *Ampelisca*, are typical of this community. Where these amphipods are present abundance may be high because they tend to congregate in communal nests. Where there are gravels and shell fragments some encrusting organisms, particularly barnacles, may also be observed.

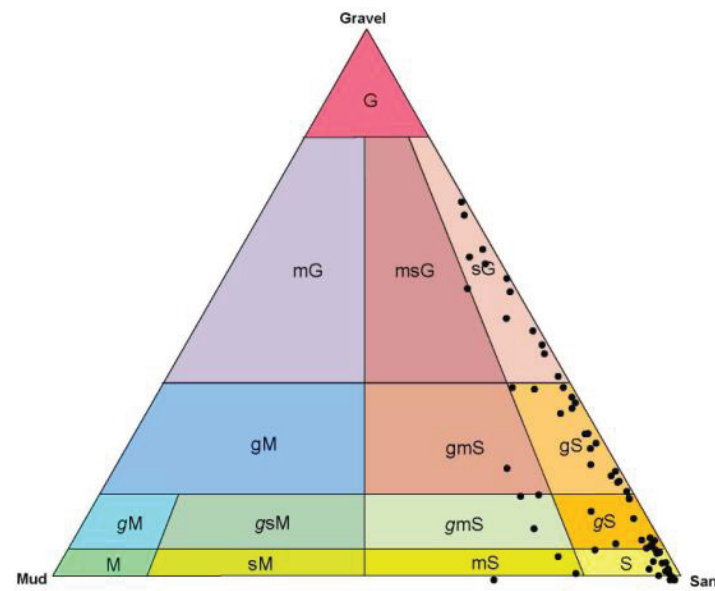


Figure 6.4.6: Folk sediment triangle for Functional Biological Community 2 with seabed image of Station 86 showing typical habitat type.



Figure 6.4.9: Key fauna for Functional Biological Community 2: The infaunal polychaetes *Ophelia borealis* and *Polycirrus*, the bivalve *Abra alba* and the amphipod *Bathyporeia*.

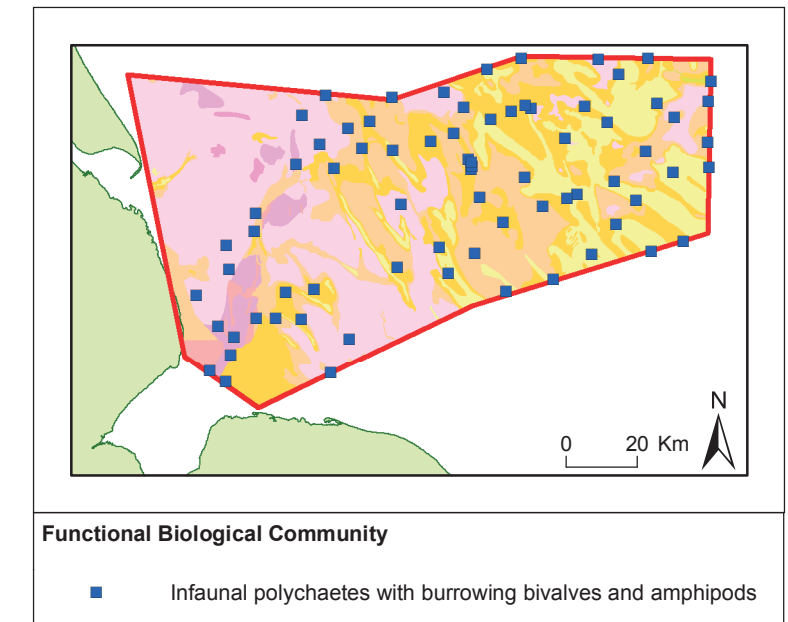


Figure 6.4.7: Distribution of Functional Biological Community 2 across the Humber REC study area.

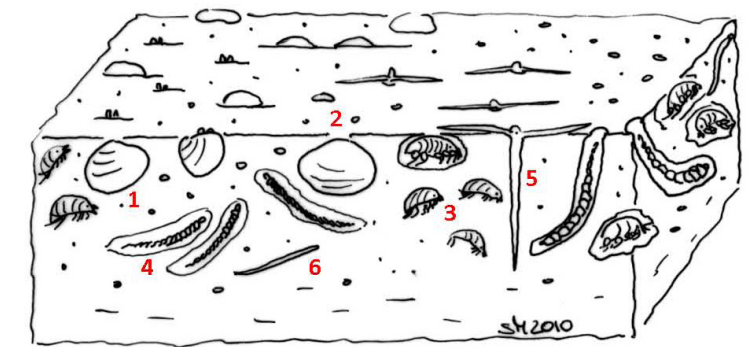


Figure 6.4.8: Diagram of Functional Biological Community 2: Species illustrated include 1. *Mysella bidentata*, 2. *Abra alba*, 3. amphipods, 4. *Lumbrineris gracilis*, 5. *Spiophanes* spp., 6. *Ophelia borealis* and other small infaunal polychaetes.

Functional Community 3 — *Sabellaria spinulosa* Reef

In areas of mixed sediments, where there is a sand component, the polychaete *Sabellaria spinulosa* is able to construct tubes, which may form aggregations from small clumps and veneers to fully elevated reef structures (Figure 6.4.10). This functional community is found mostly in the western side of the Humber REC study area (Figure 6.4.11). The energy regime is moderate providing a supply of particulate matter suitable for *Sabellaria spinulosa* which filter feeds on particulate matter in the water column.

This Functional Biological Community is highly diverse, with an average of 737 animals per grab spread over 72 taxa. The community is numerically dominated by *Sabellaria spinulosa* although there is also high abundance of bivalves of the family Mytilidae and the tube worm *Pomatoceros lamarckii* (Figures 6.4.12 and 6.4.13). In some areas there appears to be a reef like matrix of *Sabellaria* and Mytilidae. Patches of reef are mixed with communities of infaunal animals including burrowing amphipods, bivalves and other polychaetes (especially *Lumbrineris gracilis*) and epifaunal animals, particularly ascidians such as *Dendrodoa grossularia*. Where *Sabellaria* is abundant there are often high numbers of species typically associated with these reefs, in particular the pink shrimp *Pandalus* and the crab *Pisidia longicornis*.

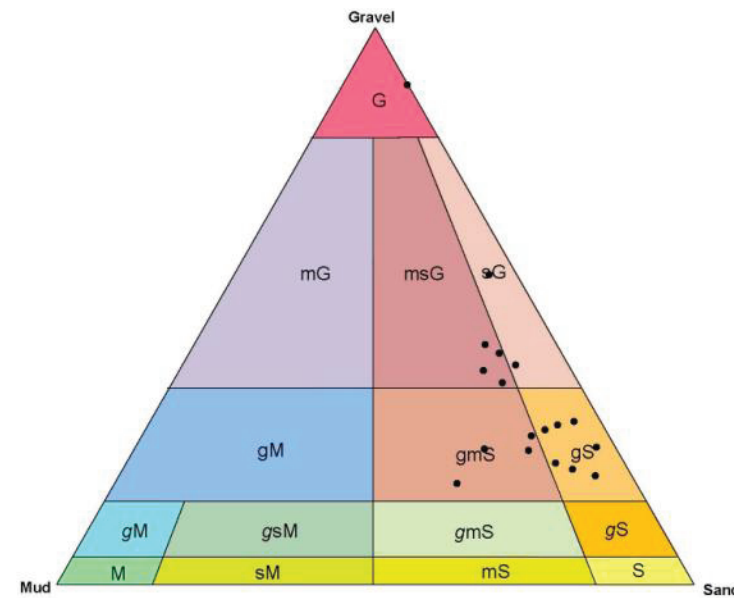


Figure 6.4.10: Folk sediment triangle for Functional Biological Community 3 with seabed image of Station 75 showing typical habitat type.

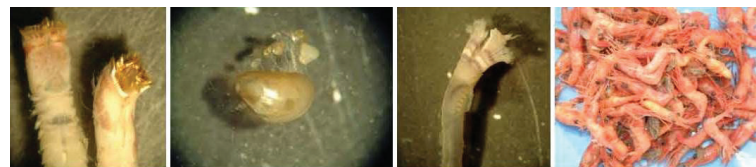


Figure 6.4.13: Key fauna for Functional Biological Community 3: *Sabellaria spinulosa*, *Mytilus* and the tube worm *Pomatoceros* and *Pandalus* spp.

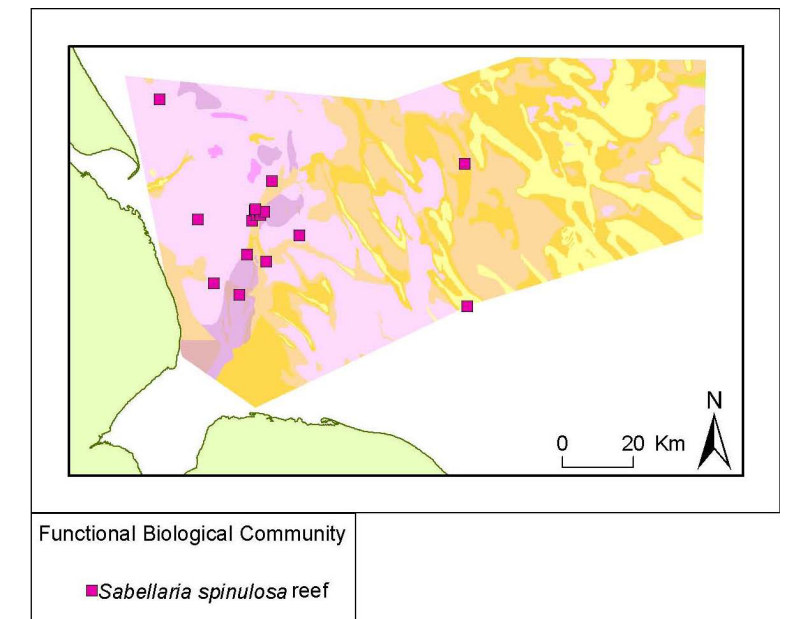


Figure 6.4.11: Distribution of Functional Biological Community 3 across the Humber REC study area.

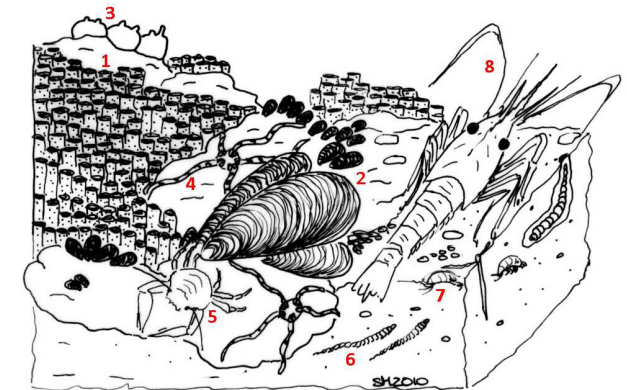


Figure 6.4.12: Diagram of Functional Biological Community 2: Species illustrated include: 1. *Sabellaria spinulosa*, 2. Mytilidae, 3. *Dendrodoa grossularia*, 4. *Ophiura albida*, 5. *Pisidia longicornis*, 6. *Lumbrineris gracilis*, 7. amphipods, 8. *Pandalus* spp.

Functional Biological Community 4 — Sparse Fauna

This functional community is found in a range of habitats with very different sediment characteristics. It is found in areas that are completely dominated by sand to very gravelly substrata as well as in areas of boulder and clay (Figures 6.4.14 and 6.4.15). The friable nature of the clay excludes almost all fauna except the most opportunistic epifaunal species and there is a very restricted range of animals that can burrow into this sediment type.

The energy level in these habitats, as in much of the Humber REC study area, is moderate although this functional community is generally limited to fairly shallow areas where there may be some exposure to wave action. This level of disturbance may be important to the community composition although the sparse fauna probably also reflects the naturally stochastic recruitment and patchy distribution of many invertebrate species.

An average of 18 individuals and 10 species per grab are found within this community. The sparse fauna is likely to include low numbers of infaunal polychaete worms such as *Ophelia borealis*, particularly in sandy habitats (Figures 6.4.16 and 6.4.17). In more gravelly habitats polychaetes such as *Glycera* spp. and *Spiophanes* spp. may also be present (Figure 6.4.17). The occurrence of gravels allows for attachment of a number of epifaunal species although the abundance of these is still low. Thus, small sea squirts, particularly *Dendrodoa grossularia*, the tube worm *Pomatoceros lamarckii* and a range of encrusting bryozoans may be found in this community. Some assemblages may also contain occasional bivalves including *Goodallia triangularis*, *Mytilus* and *Ensis*, the small urchin *Echinocyamus pusillus* and amphipods.

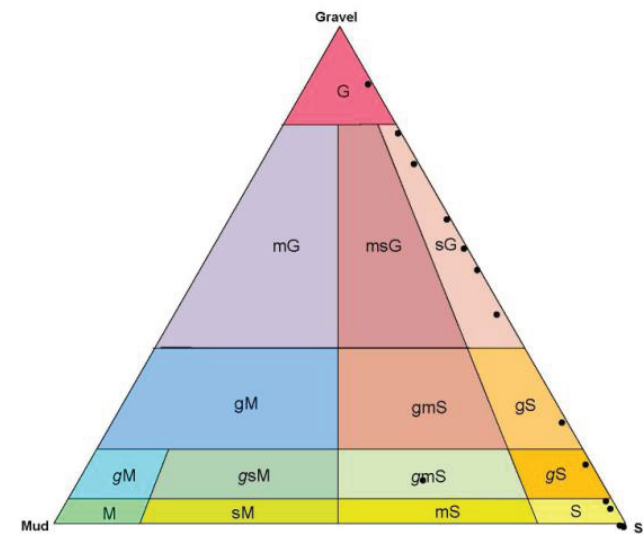


Figure 6.4.14: Folk sediment triangle for Functional Biological Community 4 with seabed images of two typical sediment type types: A. Station 16 where sand comprises over 98% of the sediment type, with occasional gravel. B. Gravel habitat at Station 74 where the gravel to sand ratio is 9:1.



Figure 6.4.17: Key fauna for Functional Biological Community 4: *Ophelia borealis* and *Glycera* spp. and Mytilidae bivalve.

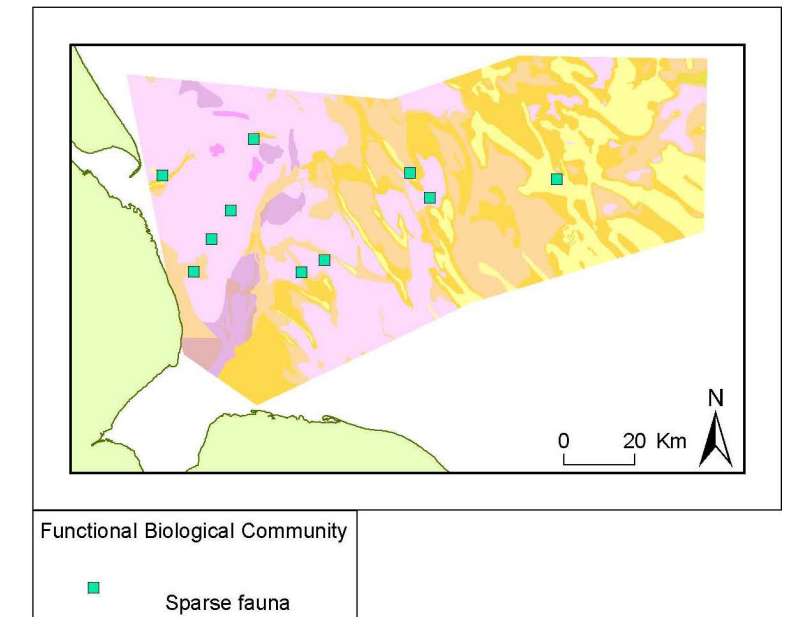


Figure 6.4.15: Distribution of Functional Biological Community 4 across the Humber REC study area.

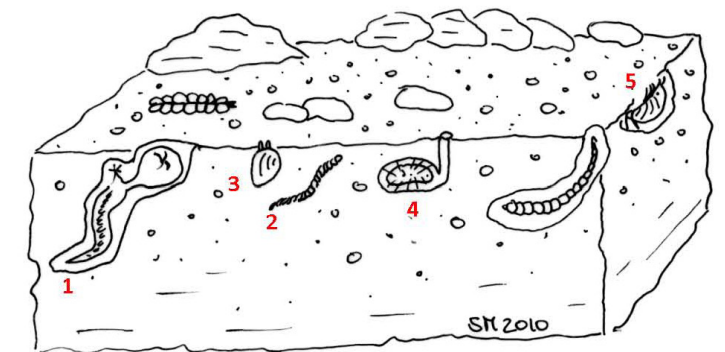


Figure 6.4.16: Diagram of Functional Biological Community 4: Species illustrated include: 1. *Glycera* spp., 2. *Ophelia borealis*, 3. bivalves, 4. *Echinocyamus* and 5. amphipods.

6.5 Linking Biological Communities with the Environment

The relationship between biological communities and their environment has been a central theme of marine research for many years (Seiderer & Newell, 1999; Newell, *et al.* 2001; Robinson *et al.* 2005; Rodil *et al.* 2009, Reiss, *et al.* 2010). More recently attempts have been made to identify environmental surrogates which could be used to predict the distribution of species or communities (McArthur, 2010; Harris, 2007). This is of particular importance to conservation management since it allows

us to predict the whereabouts of sensitive species and biodiversity hotspots as well as the impact of natural and anthropogenic induced changes in the environment.

A range of environmental variables were calculated, or extracted from models, for each of the Humber REC sampling stations in order to investigate the ways in which environmental conditions shape the biological communities in this area. The variables used are summarised in Table 6.5.1 along with the data source and type.

Variable	Source	Data Type	Details
Depth	REC	Numerical	Water depth (m) at which the sample was collected
% Sand	REC	Numerical	% sand (by weight) recorded from the Hamon grab samples. Note that % Gravel and Easting were not used in the analysis since there was a high correlation between them and % Sand. % Sand should therefore be taken as a proxy for % Gravel and Easting.
% Mud	REC	Numerical	% Mud or Silt & Clay (by weight) recorded from the Hamon grab samples.
Sorting	REC	Numerical	Sorting (standard deviation) of the grain sizes (phi) recorded from Hamon grab samples (Folk & Ward, 1957)
Skewness	REC	Numerical	Skewness (asymmetry) of the sediment composition (phi) recorded from Hamon grab samples (Folk & Ward, 1957)
Kurtosis	REC	Numerical	Kutosis (peakedness) of the sediment composition (phi) recorded from Hamon grab samples (Folk & Ward, 1957)
Bedforms	REC	Categorical	Bedforms: Sediment sheet (0), Sand waves (1), Sand banks (2), Tunnel valley (3),Glaciofluvial outwash fan (4), Submarine channel (5)
Thin Sediments	REC	Categorical	Sediments <1 m (1) Sediments >1 m (0)
Seabed Habitat	REC	Categorical	Seabed habitats described from the seabed video and stills images; Sand (1), Sandy mixed sediments (2), Coarse mixed sediments (3)
Rock Outcropping	REC	Categorical	Rock outcrop present (1) absent (0)
Slope	REC	Modelled Numercial	% Slope calculated using spatial analyst in ArcGIS
Rugosity	REC	Modelled Numercial	Rugosity calculated using the Benthic Terrain Modeler add-on for ArcGIS
Wavebase	UK SeaMap 2006	Modelled Catgeorical	Calculated from modelled wave base depth compared to actual depth (m); above wavebase (1), below wavebase (0)
Water Stratification (Summer)	UK SeaMap 2006	Modelled Categorical	Well-mixed region of freshwater influence (1), Well-mixed shelf water (2), Weakly-stratified region of freshwater influence (3), Weakly-statified shelf water (4), Stratified shelf water (5), Frontal region of freshwater influence (6), Frontal shelf water (7)
Water Stratification (Winter)	UK SeaMap 2006	Modelled Categorical	Well-mixed region of freshwater influence (1), Well-mixed shelf water (2)
Near Bottom Temperature	MyOcean (Proudman Oceanographic Laboratory)	Modelled Numerical	Near bottom temperature (°C). Note that Near bottom salinity was not used in the analysis since there was a strong correlation with near bottom temperature. Near bottom tempertature should therefore be taken as a proxy for near bottom salinity.
Current Velocity	Proudman Oceanographic Laboratory	Modelled Numerical	Maximum amplitude of the depth averaged mean spring tidal current (m/s)

Table 6.5.1: Summary of the variables used to investigate the relationship between biological communities and the environmental conditions of the Humber REC study area.

The Bio-Env routine in PRIMER V6 (Clarke & Gorely, 2006) was employed to investigate which environmental variables, individually and in combination, correlate most strongly with the patterns observed in the benthic fauna, averaged across the fifteen assemblages and the four functional biological communities (Tables 6.5.2 and 6.5.3). The degree of correlation (ps) was notably higher between the functional biological communities and the environment although it should be noted that this almost certainly is a consequence of averaging the benthic abundance data over just four categories. Nevertheless both sets of analyses showed a strong correlation between the benthic fauna and the environmental conditions across the Humber REC study area.

The composition of the sediment clearly has a strong influence on the benthic fauna in the Humber REC study area with all five of the highest individual variable correlations, for both benthic assemblage and functional biological community averaged data, being derived from the sediment composition in some way. Other important environmental influences include rugosity, depth and water stratification (Tables 6.5.2 and 6.5.3).

No. of Variables	Correlation (ps)	Variables
1	0.327	% Sand
	0.31	Seabed Habitat
	0.234	Sorting
	0.142	Thin Sediments
	0.095	% Mud
6	0.527	% Sand, % Mud, Sorting, Rugosity, Thin Sediments, Seabed Habitat
7	0.522	Depth, % Sand, % Mud, Sorting, Rugosity, Thin Sediments, Seabed Habitat
5	0.521	% Sand, % Mud, Sorting, Thin Sediments, Seabed Habitat
5	0.514	% Sand, % Mud, Sorting, Rugosity, Seabed Habitat
7	0.509	% Sand, % Mud, Sorting, Rugosity, Water Stratification (Winter),Thin Sediments, Seabed Habitat

Table 6.5.2: Summary of Bio-Env tests carried out on fourth root transformed benthic abundance data and normalised environmental data (Table 6.5.1).

No. of Variables	Correlation (ps)	Variables
1	0.327	% Sand
	0.31	Seabed Habitat
	0.234	Sorting
	0.142	Thin Sediments
	0.095	% Mud
6	0.527	% Sand, % Mud, Sorting, Rugosity, Thin Sediments, Seabed Habitat
7	0.522	Depth, % Sand, % Mud, Sorting, Rugosity, Thin Sediments, Seabed Habitat
5	0.521	% Sand, % Mud, Sorting, Thin Sediments, Seabed Habitat
5	0.514	% Sand, % Mud, Sorting, Rugosity, Seabed Habitat
7	0.509	% Sand, % Mud, Sorting, Rugosity, Water Stratification (Winter),Thin Sediments, Seabed Habitat

Table 6.5.3: Summary of Bio-Env tests carried out on fourth root transformed benthic abundance data and normalised environmental data (Table 6.5.1) averaged across the 15 benthic assemblages identified through multivariate analysis (Figure 6.5.1).

In subsequent sections of this report attempts will be made to map the Humber REC area in terms of the biotopes present. The biotope concept, first advocated by Ernst Haeckel (1876) has evolved over time and is now a tool central to marine management. Biotopes describe broad biological assemblages in combination with the environmental conditions under which they occur, namely sediment type, energy (water currents) and their biological zonation (infralittoral / circalittoral etc) (Connor *et al.* 2004). The water currents across the Humber study area are relatively consistent, mostly falling into the moderate class (Figure 2.2.1). The study area is also entirely aphotic, with insufficient sunlight reaching the seafloor for plant life to prosper. Given that there is very little variation in the energy of zonation across the Humber REC area, the combination of variables used in the EUNIS scheme may be somewhat inadequate in describing the biological and environmental resources of this area.

Bio-Env analysis identifies the ‘best ‘overall multivariable correlation or explanatory variables. However, in order to use the

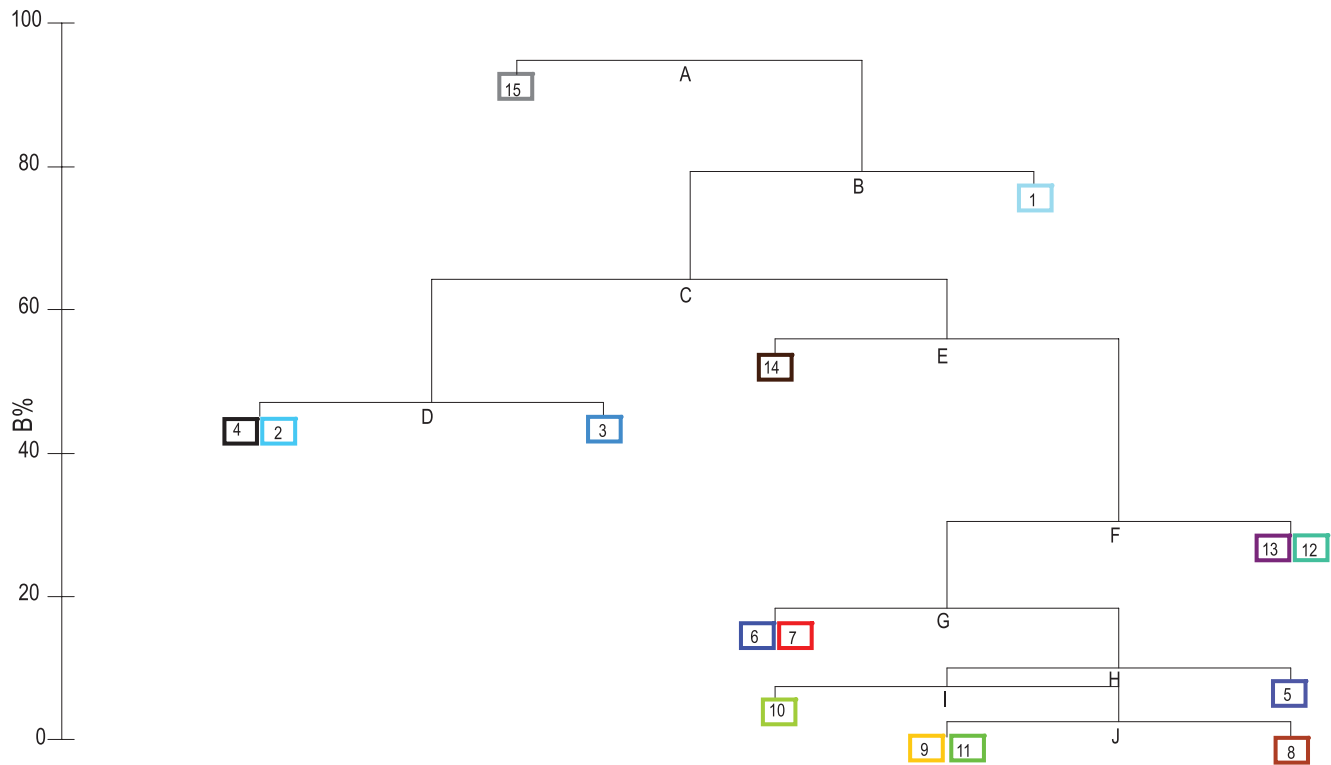


Figure 6.5.1a: Benthic assemblage (1-15) LINKTREE diagram using environmental variables as detailed in Table 6.5.1. Variables have been back-transformed so that they are presented in their correct units.

Split	R	B%	Characterising Environmental Conditions	
			Left	Right
A	0.89	95	Rugosity < 0.5	Rugosity > 0.5
B	0.76	79	% Sand > 39 or Thin Sediments present or % Mud > 0.7	% Sand < 9 or Thin Sediments absent or % Mud < 0.5
C	0.80	64	% Mud < 1.4	% Mud > 1.7
D	1.00	47	Depth < 27m or above Wavebase or Skewness > -0.1 or Thin Sediments absent or Bedform (sediment sheet) or Seabed Habitat (sand) or Slope < 0.7 or % Sand < 82 or % Mud < 1.3 or Rugosity < 1	Depth >56m or below Wavebase or Skewness > -0.4 or Thin Sediments present or Bedform (sand banks, tunnel valleys, Glaciofluvial outwash fans and submarine channels)) or Seabed Habitat (sandy-coarse mixed sediments) or Slope > 1.2 or % Sand > 83 or % Mud > 1.4 or Rugosity > 1
E	0.90	56	Sorting <1.2 or Current Speed <0.6 or % Sand >87 or Seabed Habitat (sand)	Sorting >1.8 or Current Speed >0.8 or % Sand <75 or Seabed Habitat (sandy-coarse mixed sediments)
F	0.77	30	Seabed Habitat (sandy-coarse mixed sediments)	Seabed Habitat (sand)
G	0.67	18	Thin Sediments present	Thin Sediments absent
H	0.67	10	% Slope <2 or Bedform (sediment sheet or sand waves) or Near Bottom Temperature > 5.8 or Seabed Habitat (coarse mixed sediments) or Depth <45m or % Sand <64 or % Mud <6.7	% Slope >3.6 or Bedform (glaciofluvial outwash fan or submarine channels) or Near Bottom Temperature < 5.3 or Seabed Habitat (sandy mixed sediments or sand) or Depth >52m or % Sand >70 or % Mud >7
I	1.00	7	Kurtosis >2.6 or % Slope >2 or Sorting <1.8 or Seabed Habitat (sand or sandy mixed sediments) or Skewness >0.3 or Depth >45m or Rugosity >1	Kurtosis <0.9 or % Slope <0.4 or Sorting >2.5 or Seabed Habitat (coarse mixed sediments) or Skewness <0.2 or Depth <40m or Rugosity <1
J	1.00	3	Skewness >-0.1 or Current Speed >1.1 or Near Bottom Temperature >6.3 or Water stratification (Winter) (Well mixed Shelf water) or % Sand <55 or Sorting >2.7 or Seabed Habitat (coarse mixed sediment) or % Slope >0.4 or Kurtosis <0.9	Skewness <-0.5 or Current Speed <0.9 or Near Bottom Temperature <5.8 or Water stratification (Winter) (weakly stratified region of freshwater influence, weakly stratified shelf water, stratified shelf water, frontal region of freshwater influence or fronal shelf region) or % Sand >64 or Sorting <2.5 or Seabed Habitat (sand or sandy mixed sediments) or % Slope <0.3 or Kurtosis >0.9

Figure 6.5.1b: Benthic assemblage (1-15) LINKTREE diagram using environmental variables as detailed in Table 6.5.1. Variables have been back-transformed so that they are presented in their correct units.

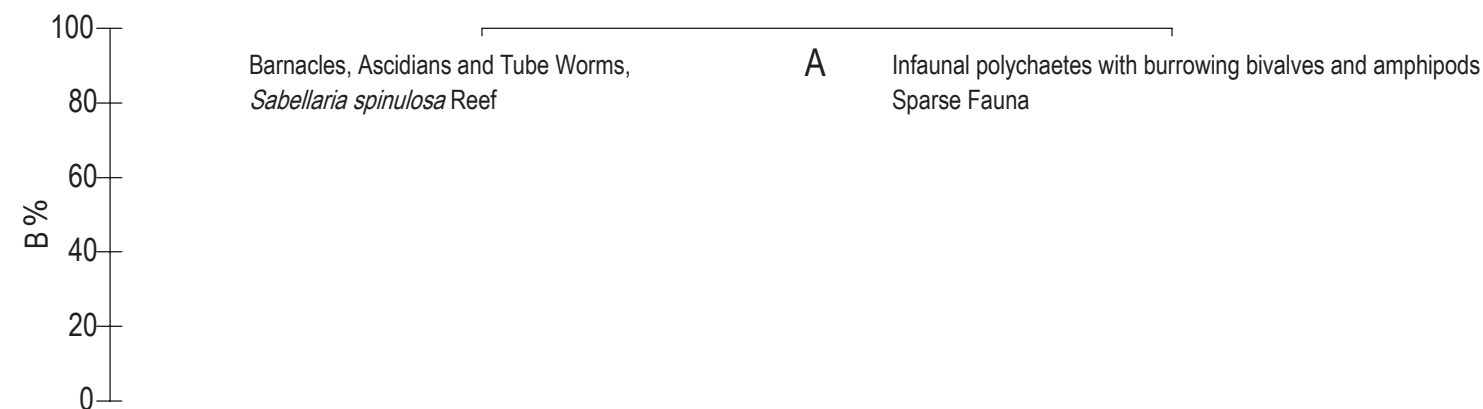


Figure 6.5.2a: Functional Biological Community LINKTREE diagram using environmental variables as detailed in Table 6.5.1.
Variables have been back-transformed so that they are presented in their original units.

Split	R	B%	Characterising Environmental Conditions	
			Left	Right
A	1	100	Sorting >2.55 or Seabed Habitat 3 or 4 or Skewness <-0.16 or Current Speed >1.04 or % Sand <63 or % Mud >3.8% or Rugosity <0.92	Sorting <1.48 or Seabed Habitat 1 or Skewness >-0.05 or Current Speed <0.96 or % Sand >65 or % Mud <3.8% or Rugosity >0.92

Figure 6.5.2b: Functional Biological Community LINKTREE diagram using environmental variables as detailed in Table 6.5.1.
Variables have been back-transformed so that they are presented in their original units.

variables as predictors of faunal distributions it is necessary to explore the species-environment relationships in more detail, and for this we have used linktree analyses. The linktree algorithm splits biological samples (or in this case assemblages and functional biological communities) in a series of divisions chosen to maximise the degree of separation between them (ANOSIM R statistic). The environmental variables which best describe each split are given alongside the ANOSIM R and the absolute difference (B%). The linktree can therefore be used, much like a dichotomous key, to predict the distribution of biological communities in areas where the environmental conditions are known.

The linktree for benthic assemblages and the broader functional biological communities identified across the Humber REC study area are presented in Figures 6.5.1 and 6.5.2 alongside the explanatory notes for each split in the tree. For ease of interpretation

the environmental variables have been back-transformed (or un-normalised) so that they appear in their original units.

The linktree is not able to split the broad functional biological communities completely, which is a function of the routine itself. However, where the functional biological communities have split, the two communities which are dominated by epifaunal species (Barnacles, Ascidians and Tube Worms and *Sabellaria spinulosa* reef) have been found to be influenced by the same set of environmental variables as have the two predominantly infaunal communities (Infaunal polychaetes with burrowing bivalves and amphipods and sparse fauna). It is unsurprising then to see that this split is best correlated with sediment sorting; the two infaunal communities being correlated with the presence of well sorted sediments (<1.48) and the epifaunal communities correlating with poorly sorted sediments, as well as other variables which also describe the difference between a substrate which can support

epifauna and one which cannot, namely well sorted sands. This may seem intuitive, but the values attached to these variables will now allow us to predict the distribution of benthic fauna in an informed and quantitative manner.

7 Integrated Assessment of Habitats and Biotopes

The integration of biotic and abiotic data is a highly complex undertaking due to the inherent differences in resolution, scale and coverage of the different data sets. The volume, resolution and extent of the data available to characterise the physical nature of the Humber REC study area is considerably greater than that available to describe the biological communities present. The former includes almost full coverage seabed morphology (SeaZone) data that allows the mapping of major bedforms such as sand banks and large sand waves (Figures 4.2.1 and 4.2.2). A combination of high resolution multibeam, sidescan sonar and sub-bottom boomer data, acquired on a broad-scale survey grid (Figure 3.1) allowed for the correlation of the seabed morphology and the underlying geology. Sediment samples collected at 209 stations also allows a range of sediment attributes to be mapped and correlated with the geology and morphology of the seafloor. In comparison there were just 135 biological observations from grab samples (also analysed for sediment), 133 from seabed images and 30 from trawl samples.

Grab samples are generally the preferred method of sampling benthic fauna providing a great deal of quantitative information about a very small area of the seafloor (0.1m²). This small scale detail is supplemented with data collected by trawls and seabed imagery which help us to identify the degree to which these samples are representative of the wider seafloor but again at a relatively small scale (10s–100s of metres). In order to predict and map the distribution of biological communities and species it is necessary to rely on the known associations and derived correlations between the physical environment and the biota it supports. This is something which is of key importance to marine management since it helps to inform the design of marine protected areas as well as allowing us to make predictions about the sensitivity of certain areas to the impacts of both natural and man-made environmental change.

The biotope concept was first advocated by Ernst Haeckel (1876) and has evolved over time to become a tool central to marine management. Biotopes describe broad biological assemblages in combination with the environmental conditions under which they occur, otherwise known as their habitat. The following sections of

this report explore two methods of mapping marine habitats and biotopes across the Humber REC study area. The first uses the European Nature Information Service (EUNIS) habitat classification system, a top-down hierarchical system which is widely used to map biotopes both in the UK and across Europe. This system maps the environmental conditions in terms of the sediment composition, the biological zone (littoral, infralittoral, circalittoral or deep circalittoral) and the energy of the water currents and then describes the fauna and flora that occur within those habitat classes. The second method uses habitat suitability modelling whereby the range of environmental conditions under which a biological community occurs is determined through examination of the recorded distribution as well as expert judgement and the output of statistical investigations into the relationships between faunal groups and their environment (Chapter 6.5). In this sense the second method is considered to be more flexible and intuitive, as many biological communities occur under a number of different environmental conditions. Finally, these two methods were combined to give a model of predicted biotopes throughout the Humber REC study area.

7.1 EUNIS Biotope Classification

The EUNIS habitat classification system was developed by the European Environment Agency (<http://eunis.eea.europa.eu/introduction.jsp>) between 1996 and 2001 in collaboration with experts from across Europe. The marine section of this classification system has direct equivalents in the UK's own system 'The Marine Habitat Classification for Britain and Ireland' (Connor *et al.* 2004) <http://www.jncc.gov.uk/page-1584>. The present version of this classification was developed during the JNCC's Marine Nature Conservation Review (MNCR) hence their coding system is commonly referred to as MNCR biotope codes.

The EUNIS scheme has a hierarchical structure, with progressive layers (1–7) dealing with different features of the biotope. Level 1 splits the marine environment (A) from terrestrial environments (B–X) and levels 2, 3 and 4 (for sediment habitats only) split the habitats down further based on physical attributes alone. Beyond this the classification scheme splits the habitats into biotopes based on the faunal communities present. Since upper levels (1–3/4) of the EUNIS hierarchy are based on environmental

characteristics alone, it is possible to use this system to model the distribution of biotopes. Methods to model Eunis level 3 habitats on the basis of physical data were developed during the South Coast REC (James *et al.* 2010). These methods were developed further in the current Humber REC study to produce a habitat model (EUNIS level 4) as described in subsequent sections of this report.

7.1.1 Development of a EUNIS Level 4 Model

The initial stages of creating a EUNIS level 4 model of the Humber REC study area required the generation of full coverage maps detailing the biological zones, substrate type and the energy at the seabed. A summary of the process through which these maps were developed is given below and more detailed technical information regarding data processing is provided in Appendix E.

Biological Zones

The EUNIS classification scheme divides the marine environment according to four recognised biological zones (littoral, infralittoral, circalittoral and deep circalittoral). The littoral zone, otherwise known as the intertidal zone, is the area between high tide and low tide. Since the entire Humber REC study area is covered by water at all times no areas fall into this classification.

The infralittoral zone is defined as the area of the sublittoral environment which is dominated by photosynthetic organisms. Its lower limit can therefore be approximated by the depth at which light reaching the seabed is 1% of the surface irradiance (Coggan and Diesing, 2009). A map of the depth of light attenuation (to 1% irradiance) covering the study area was sourced from UKSeaMap (2006). This map was combined with the seabed bathymetry (Figure 2.1.1) in order to derive a map of the photic (infralittoral) and aphotic (circalittoral and deep circalittoral) zones (Figure 7.1.1). The Humber REC study area was found to be almost entirely aphotic. A very small photic zone was identified to the far south west of the area, however since no samples were collected in this zone, and no photosynthetic organisms were identified in nearby sampling stations, it was decided to exclude the photic zone from our model making the assumption that the whole REC study area is aphotic (circalittoral or deep circalittoral).

The lower limit of the circalittoral zone is not clearly defined within the EUNIS habitat classification scheme and so has been

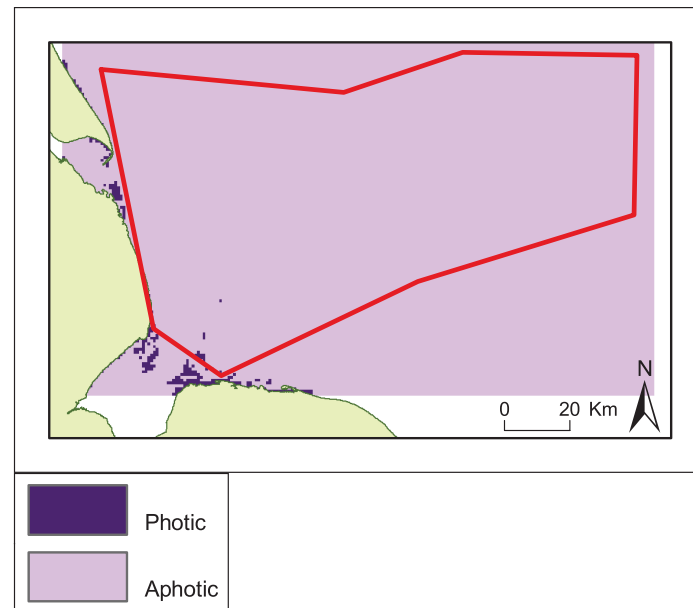


Figure 7.1.1: Photic and aphotic zones of the Humber REC study area, derived from the UKSeaMap light attenuation map (Connor *et al* 2006) and seabed bathymetry (© British Crown & SeaZone Solutions Ltd. Licence No. 052008.012. All rights reserved.)

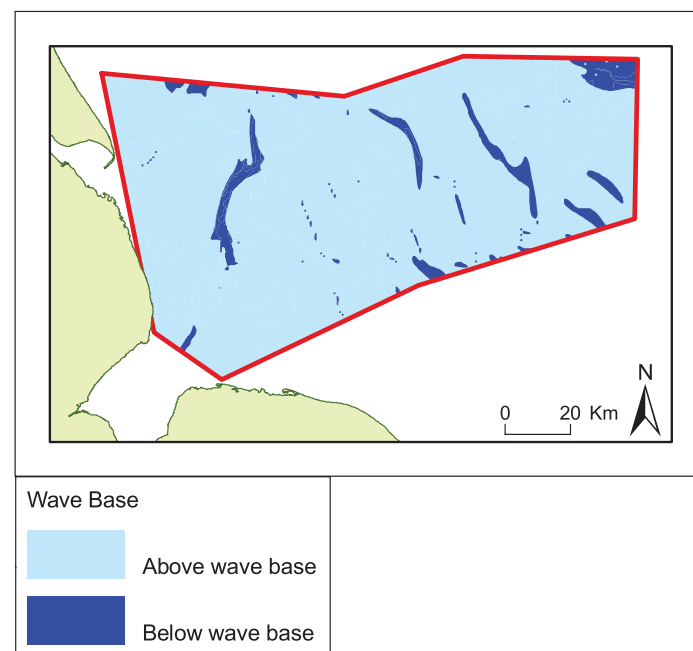


Figure 7.1.2: Areas above and below the wave base, derived from the UKSeaMap (Connor *et al* 2006) and seabed bathymetry (© British Crown & Seazone Solutions Ltd. Licence No. 052008.012. All rights reserved.)

approximated as the depth of water at which the passage of a wave is still able to disturb the seabed (Coggan and Diesing, 2009). The circalittoral zone has therefore been classified as the area above the wavebase in our model and anything below has been classified as deep circalittoral. The depth of the wavebase was sourced from UKSeaMap (2006) and this was combined with seabed bathymetry in order to split the study area into regions above (circalittoral) and below the wavebase (deep circalittoral) (Figure 7.1.2).

Substrate Type

Level 2 in the EUNIS habitat classification scheme splits the sublittoral environment by the mobility of the substrate, splitting rock and other hard substrates from sublittoral sediments. The sublittoral

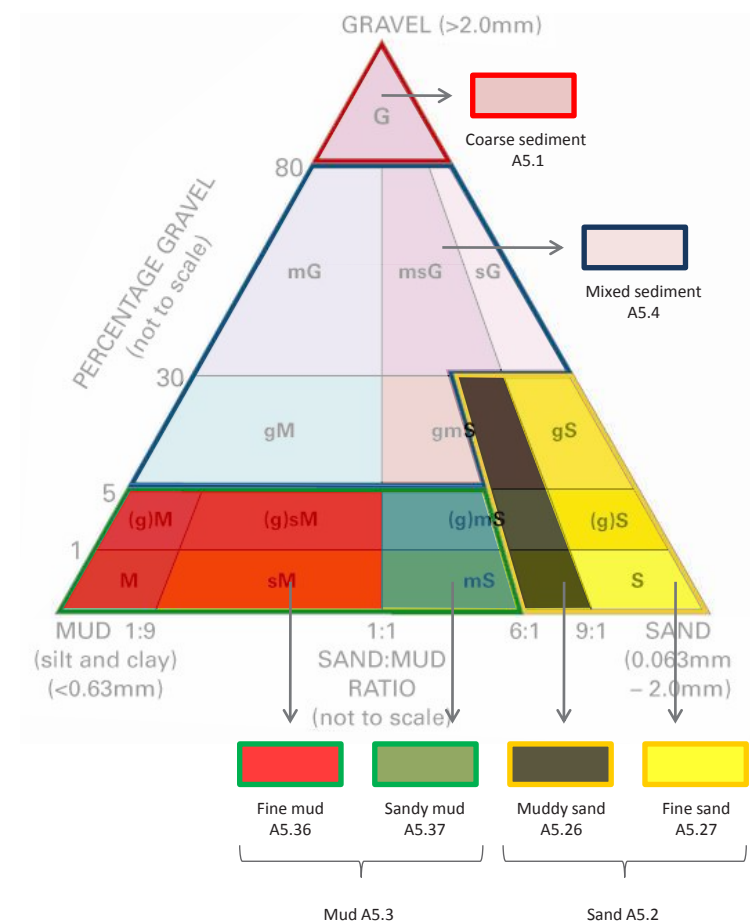


Figure 7.1.3: Folk sediment trigon, modified to show aggregation of classes into four main sediment classes (coarse, mixed, sand, mud) at level 3 EUNIS; and division into further categories at level 4 EUNIS.

sediments are then split further, at level 3 in the classification scheme, into coarse sediments, sands, muds and mixed sediments. Methodologies developed as part of the South Coast REC to derive these four sediment classes from the Folk sediment classification scheme (James *et al*, 2010) were further developed to incorporate the more detailed sediment divisions splitting sands and muds into fine muds, sandy muds, muddy sand and fine sand, which appear in Level 4 of the EUNIS scheme (Figure 7.1.3).

The majority of the Humber REC study area has been classified as sediment and so by aggregating the folk classification as outlined in Figure 7.1.3 it is relatively simple to produce a substrate map

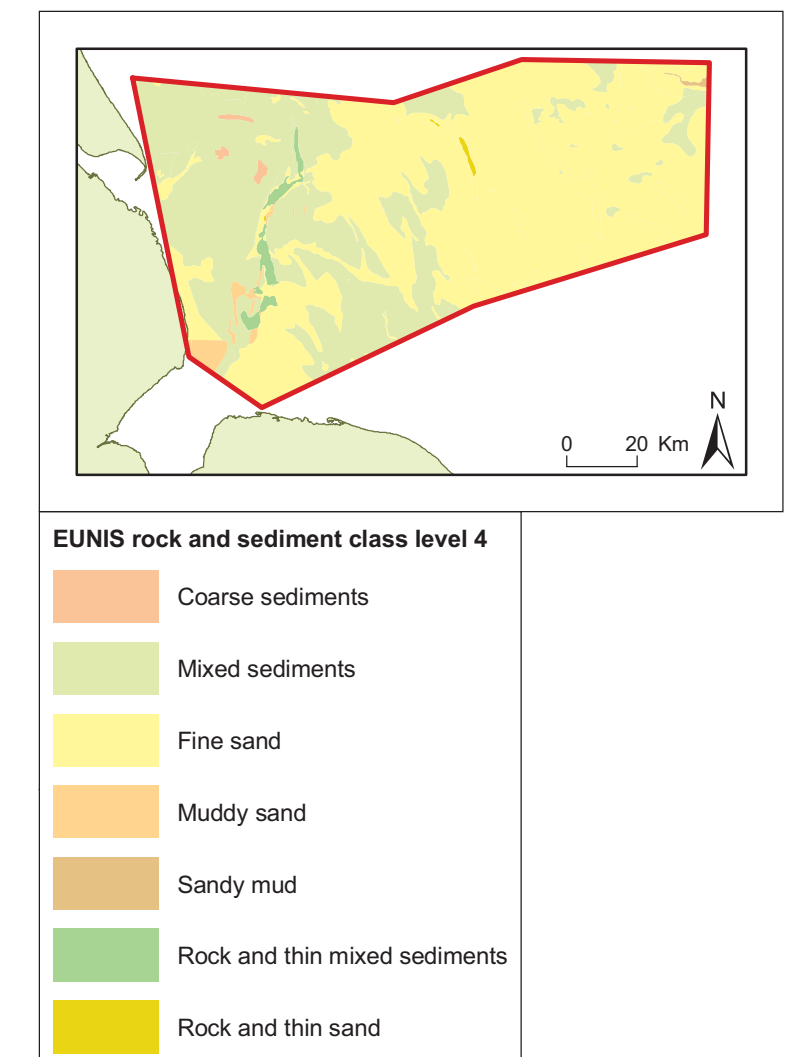


Figure 7.1.4: Eunis Level 4 substrate map.

that is consistent with the EUNIS classification scheme. However, outcropping bedrock was observed at the base of the Silver and Sole pits (Figures 4.2.14 and 4.2.15). These areas were overlaid with a thin layer of sediment and so do not fit well into either the rock or the sediment classes described in the EUNIS scheme. The new ‘rock and thin sediment’ classes proposed in the South Coast REC and eastern English Channel Synthesis project (James *et al.* 2011) were therefore adopted as they better reflect the habitat observed in this area of the Humber. The rock and thin sediment classes allow for the coexistence of rock and thin sediments, as a transitory class between pure rock and pure sediment habitats. As a temporary measure the rock and thin sediment class has been placed within the existing Level 2 rock group and then subdivided according to the four broad sediment types (coarse sediments, sands, muds and mixed sediments). In this way it was possible to derive a complete substrate map of the area as shown in Figure 7.1.4.

Energy

Rock categories are subdivided within the EUNIS scheme based on energy at the seabed, and this has therefore been applied to

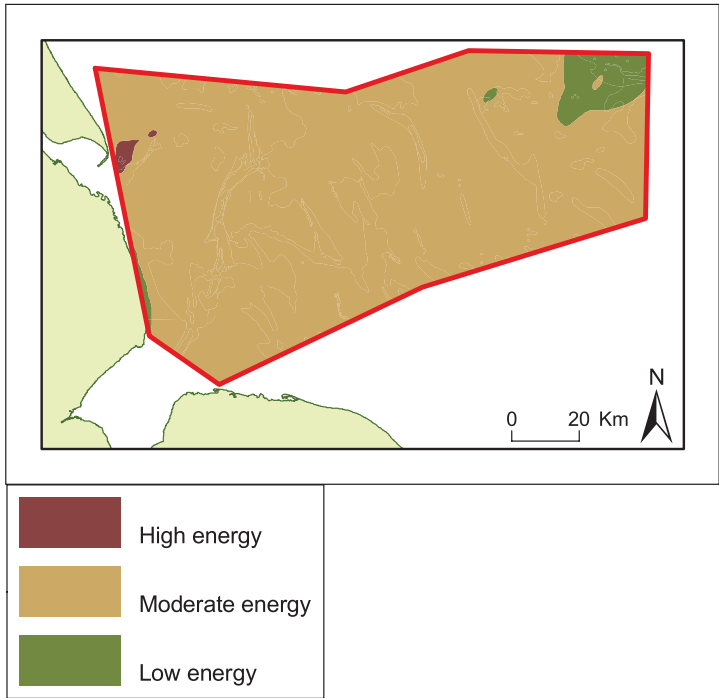


Figure 7.1.5: Tidal energy map based on maximum spring tide velocity (low <0.5m/s, moderate 0.5–1.5m/s and high >1.5m/s).

the rock and thin sediment classes to provide consistency between our model and the EUNIS scheme. Energy at the seabed has been derived from modelled tidal velocities for the maximum spring tide supplied by Proudman Oceanographic Laboratory (POL). The tidal data has been categorised according to the EUNIS classification of low <0.5m/s, moderate 0.5–1.5m/s and high >1.5m/s (Figure 7.1.5).

The biological zones, substrate types and energy classes were then combined to produce a complete coverage EUNIS level 4 map (Figure 7.1.6). Although energy levels are not used within the EUNIS scheme to subdivide sediment habitats they have been left on the model output as annotations as it thought likely that this may play some role in influencing the biological communities.

7.1.2 Point Biotope Classifications

All environmental data collected at each of the biological sampling stations was re-examined and compared with the modelled EUNIS level 4 classifications and where necessary the stations were re-classified to more accurately reflect the habitat sampled at that

location. The model gave a good representation of the EUNIS level 4 habitats present across the area with 92% agreement with habitats derived from sample data. There were instances where the model did not accurately reflect the sample data, but in all cases this was thought to be a reflection of small scale variation in the environmental conditions, most notably the sediments. A summary of the discrepancies between the model and the classifications based on point data are given below in Table 7.1.1.

It is widely accepted that the data used to develop the sublittoral component of the EUNIS classification system was lacking and in some cases wholly inadequate. For example some level 6 biotopes are described on the basis of a single sample. These data gaps mean that the classification scheme has been developed on a somewhat *ad hoc* basis and there are therefore inconsistencies in the way in which biological communities are split. For example Level 5 biotopes are described in some instances as broad functional groups such as ‘Semi-permanent tube-building amphipods and polychaetes in sublittoral sand’ and in

Modelled EUNIS 4	Actual EUNIS 4	Evidence for Difference	Reason for Discrepancy	Stations
A5.44 — Circalittoral mixed sediment	A4.93 — Moderate energy, circalittoral rock and thin mixed sediment	Seabed images show boulder clay out cropping through the sediment	Sub-bottom data which is used to derive areas of thin sediment over rock is unreliable at the surface and so some areas of rock and thin sediment may be missed	74, 111
A5.44 — Circalittoral mixed sediment	A5.25 — Circalittoral Sand	Particle Size Analysis on the grab sample revealed <30% gravel	Variation in sediment on a more localised scale than the model. Model based on more evidence than just point PSA data	39
A5.25 — Circalittoral Sand	A5.44 — Circalittoral mixed sediment	Particle Size Analysis on the grab sample revealed >30% gravel	Variation in sediment on a more localised scale than the model. Model based on more evidence than just point PSA data	69, 118, 137, 28
A4D.94 — Deep circalittoral rock and thin mixed sediment	A4D.92 — Deep circalittoral rock and thin sand	Particle Size Analysis on the grab sample revealed <30% gravel	Variation in sediment on a more localised scale than the model. Model based on more evidence than just point PSA data	95
A5.44 — Circalittoral mixed sediment	A5.14 — Circalittoral coarse sediment	Particle Size Analysis on the grab sample revealed >80% gravel	Variation in sediment on a more localised scale than the model. Model based on more evidence than just point PSA data	128, 125
A5.45 — Deep circalittoral mixed sediment	A5.27 — Deep circalittoral sand	Particle Size Analysis on the grab sample revealed <30% gravel	Variation in sediment on a more localised scale than the model. Model based on more evidence than just point PSA data	3

Table 7.1.1: Summary of discrepancies between the modelled Level 4 Biotopes and the Level 4 biotopes assigned based on evidence collected from the sampling stations.

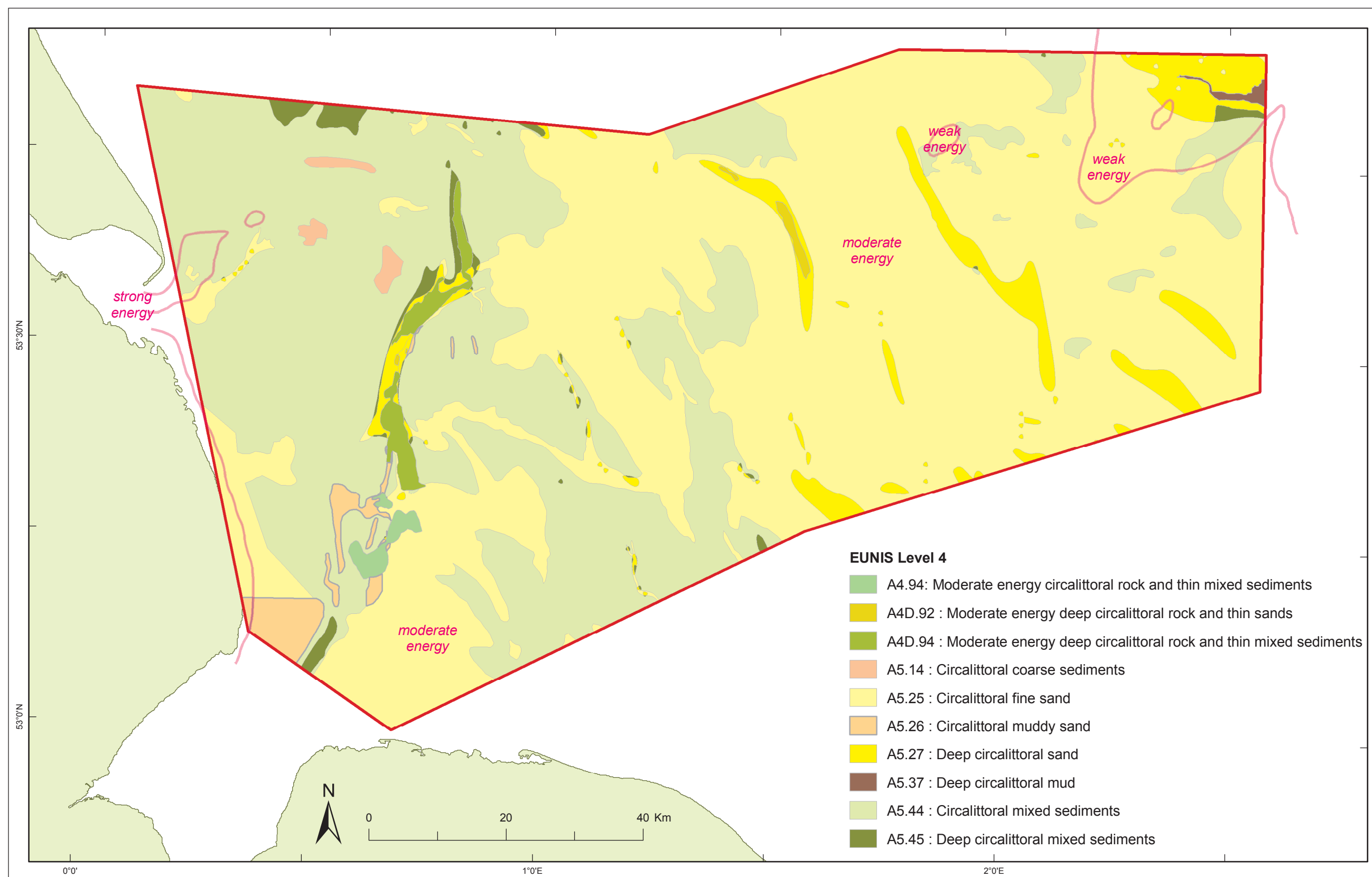


Figure 7.1.6: Level 4 modelled EUNIS map.

other instances by specific combinations of species such as '*Abra prismatica*, *Bathyporeia elegans* and polychaetes in circalittoral fine sand'. In order to classify the Humber REC sampling stations in a consistent and repeatable manner, the EUNIS level 4 classifications (derived from point data) were combined with the assigned Functional Biological Community (Chapter 6.4) to give broad level biotope descriptions (equivalent to EUNIS level 5). Where there were sufficient samples, a more detailed biotope description based on species composition was also given (equivalent to EUNIS level 6). The most descriptive biotope classifications assigned to each station now follow as Biotope Summaries.

7.1.3 Biotope Summaries

The biotope summaries for each of the six Eunis Level 3 classes and their associated higher levels from 4–6 are outlined below. They include a brief description of the physical and biological characteristics of each biotope, illustrated with relevant sea bed photographs. The summaries include, where available, illustrations of multibeam, sidescan sonar and boomer sub-bottom at selected stations or in close proximity. There is also a histogram of the mean grain size distribution for the collective samples within each of the six classes. EUNIS and MNCR codes having elements in parenthesis indicate potential new biotope classes identified during the course of this study. These have a combination of taxa or environmental conditions which are considered to be significantly different to the biotopes listed in the EUNIS habitat scheme.

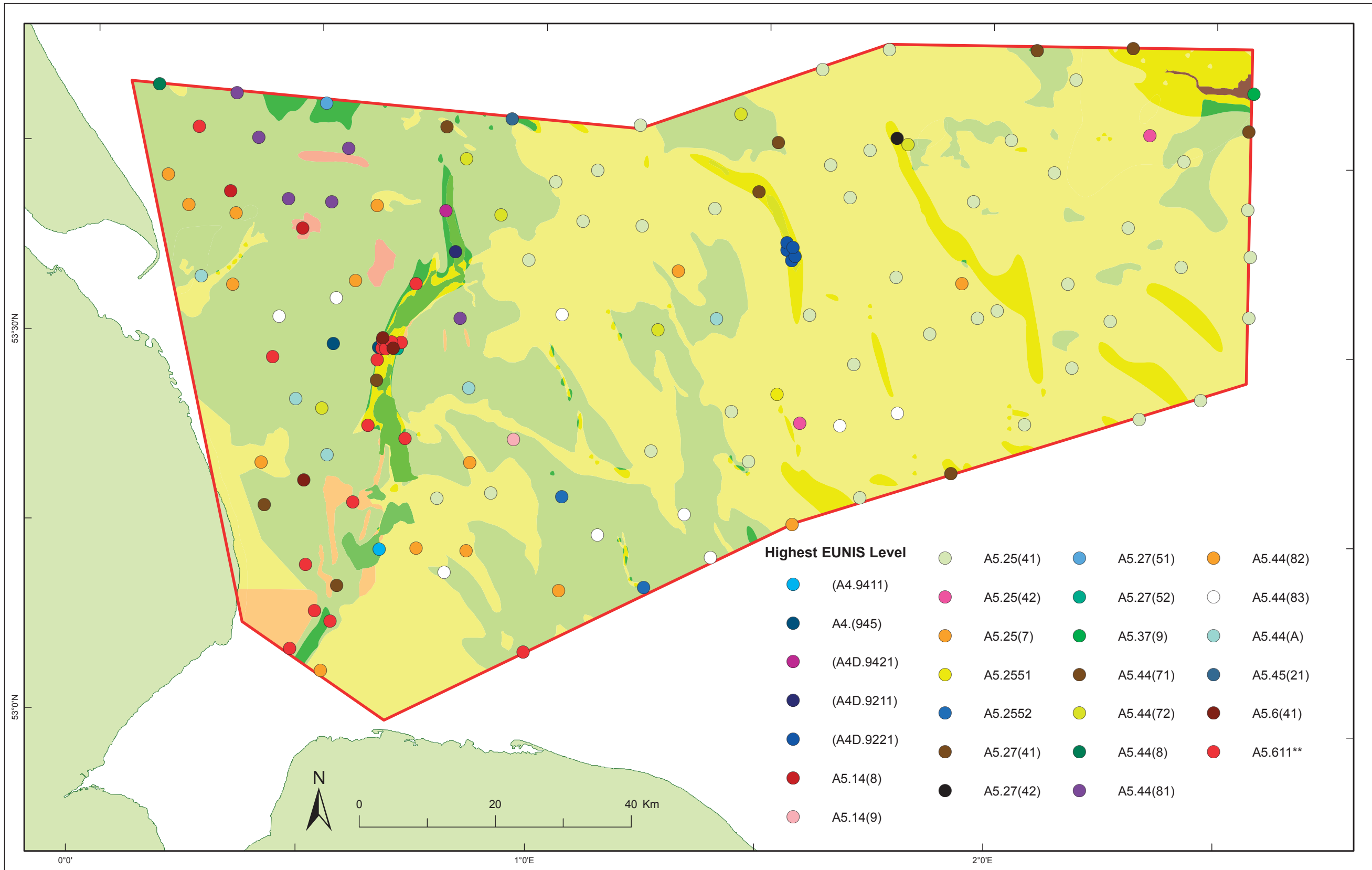
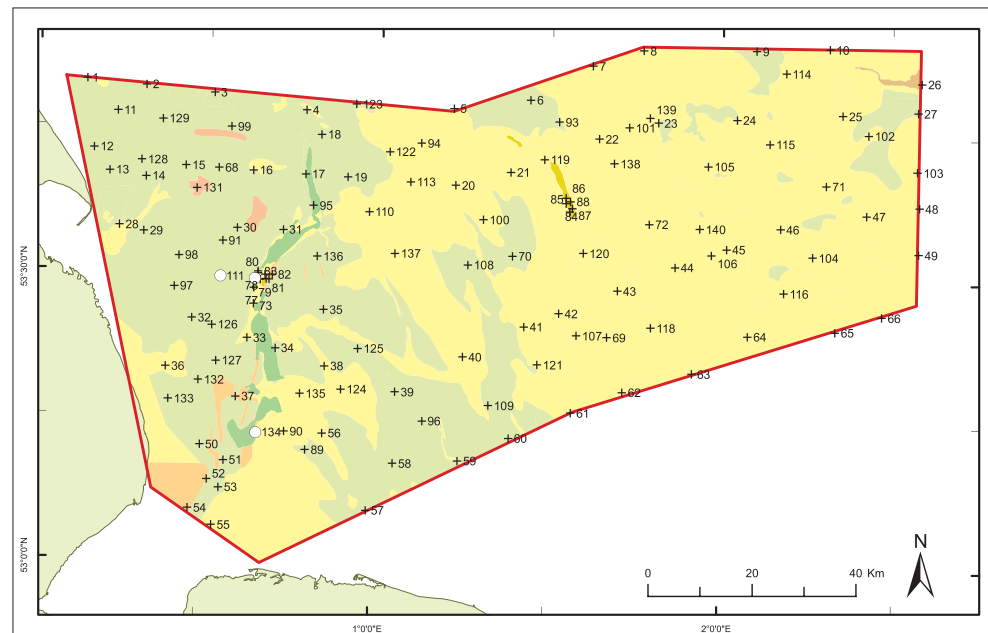
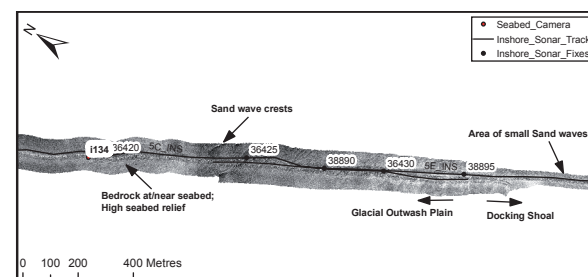


Figure 7.1.7: EUNIS habitat classes for the Humber REC sample stations overlaid on the EUNIS Level 4 model.

A4.(9) — Moderate energy, circalittoral rock and thin sediment (CR.RTS)



Location of stations assigned to the EUNIS Level 3 Habitat A4.(9) (white circles), in relation to seabed character.



Multibeam echo sounder (backscatter)

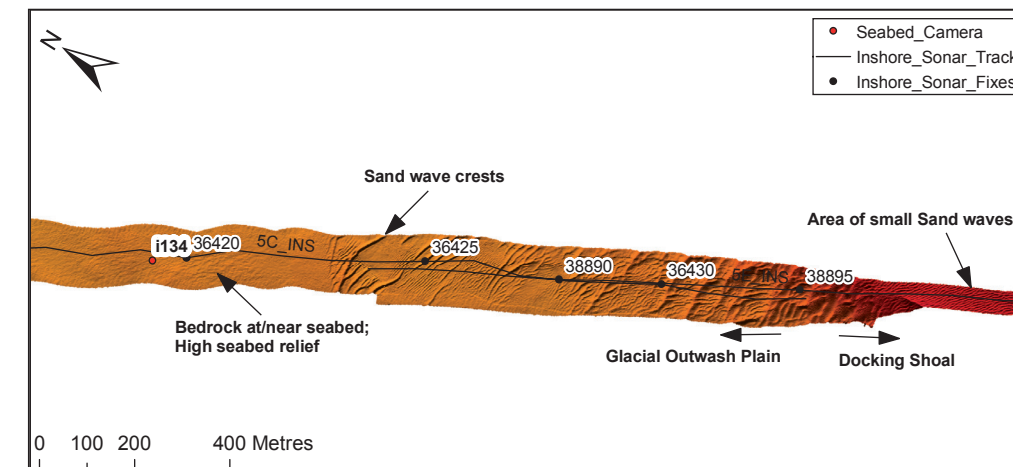
Solid Geology

For all sample stations, Cretaceous Chalk subcrops the Quaternary units and seabed sediments where present. Chalk immediately underlies thin (if present) seabed sediments at each of the classified stations with the exception of 111, where the Quaternary Bolders Bank Formation sits atop the Chalk. The Chalk is a fine-grained limestone. Flint, which formed by silica dissolution precipitating along bedding planes may be present as gravel or cobbles. The Bolders Bank Formation, is a hard glacial boulder clay (Till), and considered 'rock' with respect to biota due to the similar ways in which it is colonized.

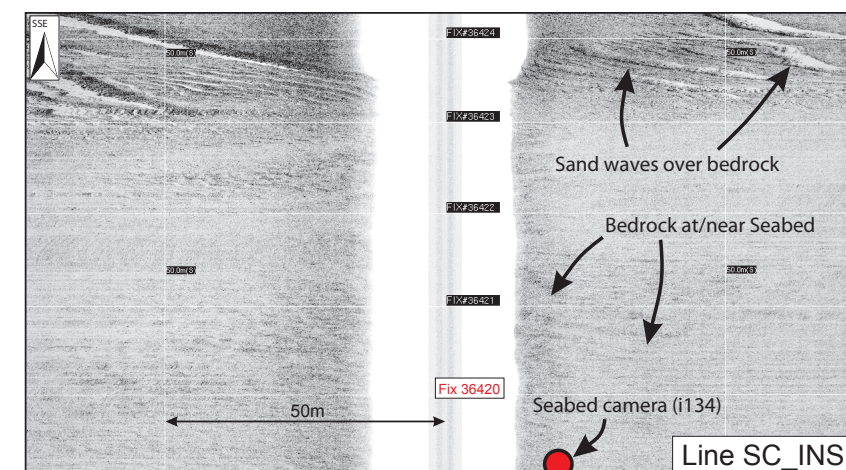
Exposures of Chalk at the seabed commonly cause high seabed relief due to differential weathering of the exposed horizons which commonly dip to the west in the Silver Pit region.

Superficial Sediment

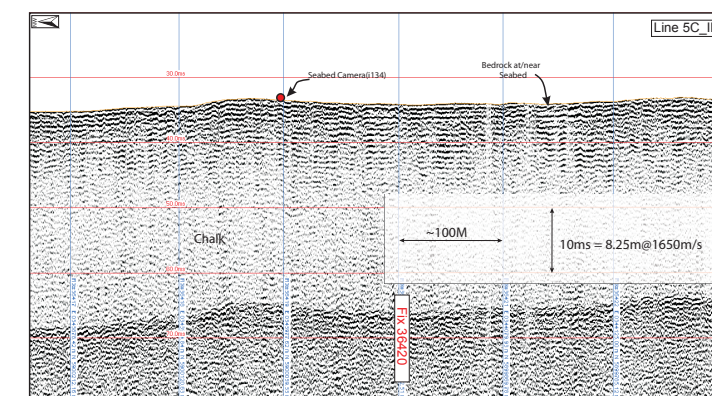
Seabed sediments are thin or absent at these sample sites, even where sand waves are present on the sidescan sonar image bedrock is exposed within the troughs. Within the the glacial outwash plain and the Silver Pit to the north, seabed sediments are scarce due to modern very active bottom currents which are of sufficient strength to prevent significant deposition of sand or gravelly sand which would otherwise be present. The absence of sediment (sandy gravel) at sample station 111 is more likely caused by a compounding of modern and historical oceanographic forcings. The area west of the Silver Pit comprises very gravelly sediment with common cobbles and boulders. This is particularly true along the western rim of the Silver Pit. It is unlikely that since the last marine transgression there has been any widespread deposition of fine-grained sediment in this area. Regardless of this, strong coastal currents have winnowed most fine-grained material from the Bolders Bank Formation at the seabed. Station 111 is the only sampled location within the REC area where the boulder clay is actually present at seabed, indicating current strengths sufficiently strong to remove the gravel and cobbles in addition to the finer grained material.



Multibeam echo sounder (bathymetry).



Sidescan sonar (backscatter).



Seismic section.

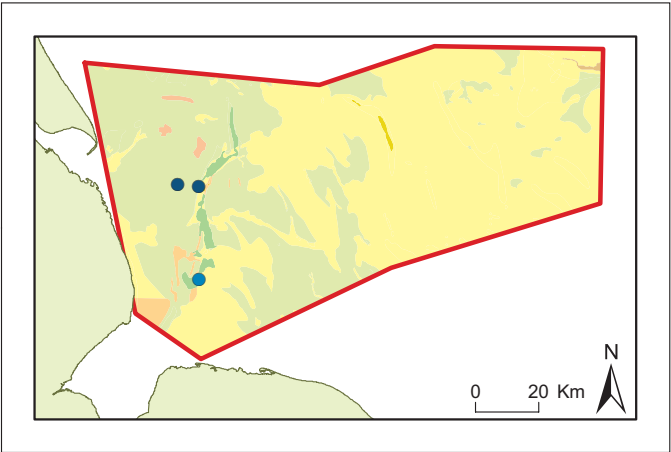
(A4.9) — Moderate energy, circalittoral rock and thin sediment (CR.DRTS)

Level 4 (Biotope Complex)

Level 5 (Biotope) & Level 6 (Sub-biotope)

Level 5 (Biotope)

A4.(94) = CR.RTS.Mx
Moderate energy, circalittoral rock and thin mixed sediment

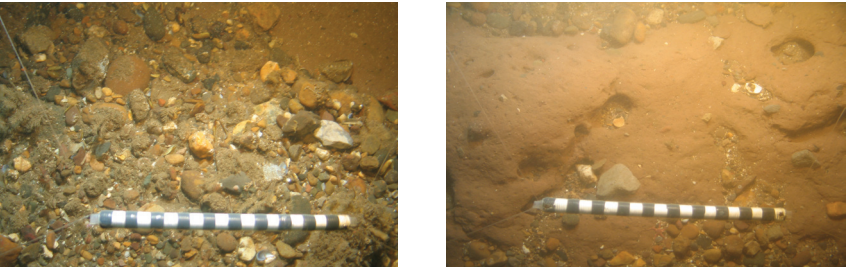


Location of stations within the EUNIS A4.94 biotope complex, in relation to seabed character. Circle colours: dark blue = A4.945, light blue = A4.9411.

This is a newly defined biotope complex which reflects the presence of boulder clay (classified as circalittoral rock) covered in a thin layer of sediments that have been extensively recorded in the South Coast REC study area. The boulder clay is highly compacted, that in terms of the biology of the area, is a 'rock' type habitat that can only be inhabited by a few high robust burrowing animals such as piddocks. However, where the surface of the boulder clay is exposed, it does erode very slowly which prevents the settlement of encrusting organisms.

This biotope complex was only recorded at three stations in the west of the study area where boulder clays are present.

The occurrence of characteristic species and life forms enabled a more precise classification at EUNIS level 5 or 6.

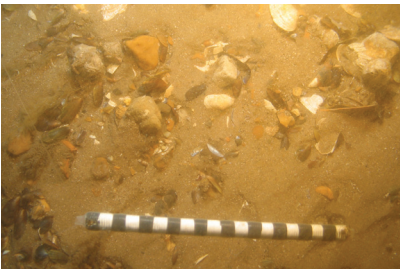


Seabed images of Station 74 showing emergent boulder clay (top right of the photograph) and a layer of overlying mixed sediment and Station 111 with much bare boulder clay visible.

A4.(941) = CR.RTS.Mx.PoBlvAmp
Infaunal polychaetes with burrowing bivalves and amphipods in thin mixed sediment

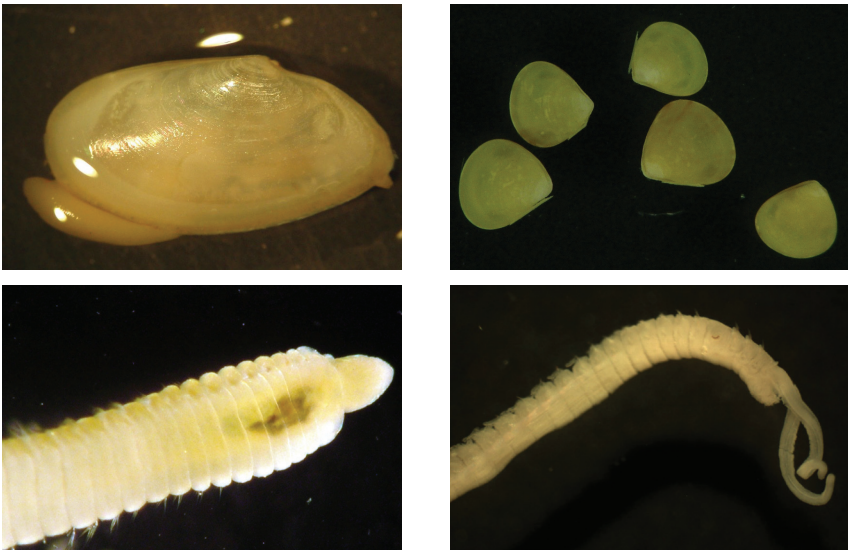
Recorded at Station 134, this biotope typically occurs in areas of moderate energy tide-swept areas where rock is associated with mobile sand or gravel. This station was assigned to a Level 6 sub-biotope on the basis of the species present.

A4.(9411) = CR.RTS.Mx.ApriBatPo
Abra prismatica, *Bathyporeia elegans* and polychaetes in thin mixed sediment



Seabed image showing the mixed sediments at Station 134.

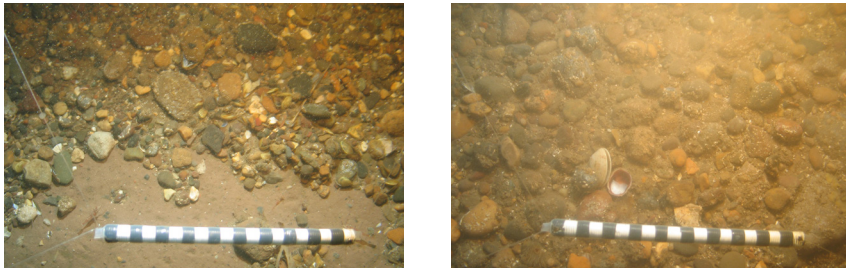
The grab samples were dominated by bivalves including *Goodallia triangularis*, *Nucula* and *Abra prismatica*, polychaetes such as *Lumbrineris* spp., *Nephtys* spp. and *Polydora*. There was also a wide range of hydroids and bryozoans present, reflecting the presence of attachment sites in the form of gravels and shell fragments. The amphipod present at this station was *Ampelisca*.3



Specimen photographs of *Abra prismatica* (top left), *Polydora* sp. (top right), *Goodallia triangularis* (bottom left) & *Lumbrineris* (bottom right) (© seaseasurvey.co.uk)

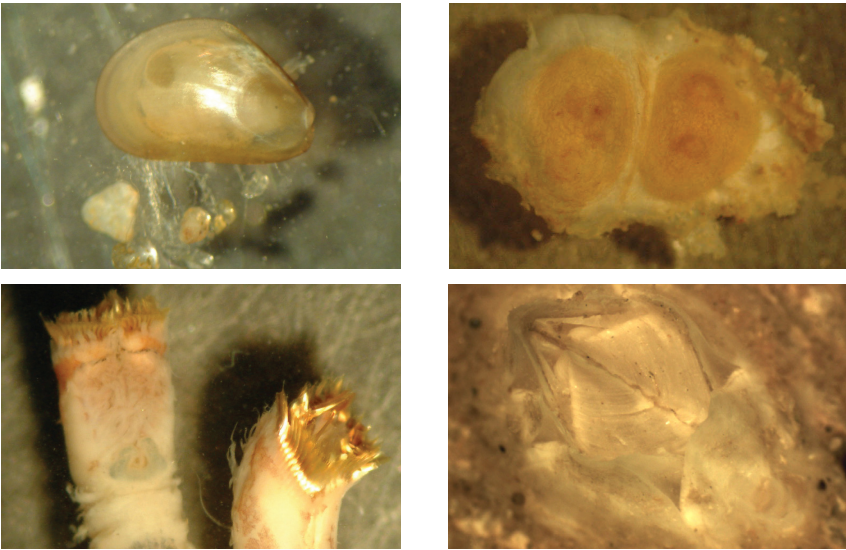
A4.(945) = CR.RTS.Mx.SpFa
Sparse fauna in thin mixed sediment

This biotope was found at two stations, 74 and 111, where there is low abundance and diversity of animals. An average of 23 individuals per grab were found in these two samples. Areas of emergent boulder clay and mobility of fine sediments may be responsible for the sparseness of the fauna although this may also be due to the natural patchiness in the distribution of many species.



Exposed boulder clay with nearby areas covered with a thin veneer of mixed sediments (Station 74) and thin sediment (Station 111).

Species sampled in the Hamon grab include Mytilidae, *Sabellaria spinulosa*, the ascidian *Dendrodoa* and the barnacle *Balanus crenatus*. However, all were present in very low abundance.



Specimen photographs of *Mytilidae* (top left) and the ascidian *Dendrodoa* (top right), *Sabellaria spinulosa* (bottom left) and *Balanus crenatus* (© seaseasurvey.co.uk)

Figure 1: Map of the study area. The map shows a grid of 10m x 10m cells. A red dot marks the location of the seabed camera (i17). A black arrow points to a location labeled 'Bedrock Outcrop'. A scale bar indicates 50m. A compass rose shows North (N) and East (E). A label 'Line 17_N_100A' is present in the top right corner.

Line 17E

Seabed Camera@134

Chalk at/near Seabed

Chalk

FW 26705

~100M

10ms = 8.25m@1650m/s

260

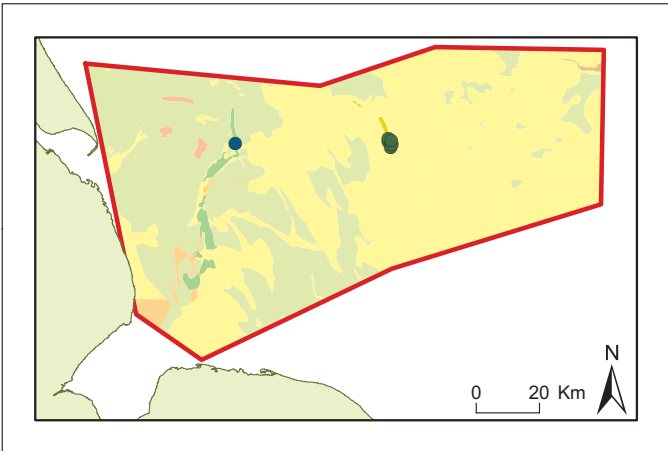
(A4D.9) — Moderate energy, deep circalittoral rock and thin sediment (CR.DRTS)

Level 4 (Biotope Complex)

Level 5 (Biotope) & Level 6 (Sub-biotope)

Level 5 (Biotope)

(A4D.92) = CR.RTS.DRTS.S
Moderate energy, deep circalittoral rock and thin sands



Location of stations within the EUNIS A4D.92 biotope complex, in relation to seabed character. Dark green = A4D.9211, light green = A4D.9221.

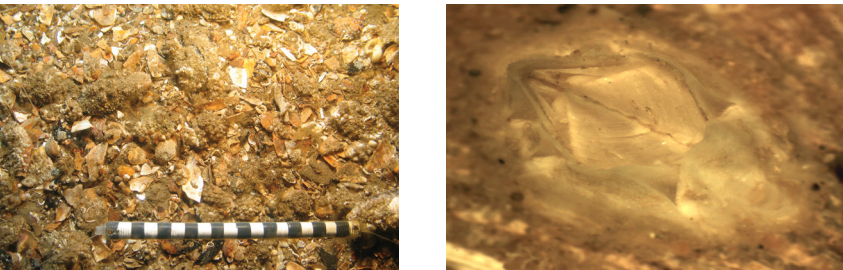
This biotope complex was found at 6 stations and assigned to two different biotopes: A4D.922 and A4D.922.

(A4D.922) = CR.RTS.DRTS.S.BAscPo
Barnacles, ascidians and tube worms on circalittoral rock and thin sands

Only one station, Station 95, was assigned to this biotope classification and further assigned to Level 6 based on the species present.

(A4D.9221) = CR.RTS.DRTS.RTS.BcreCdunDgro
Balanus crenatus, *Chone duner* and *Dendrodoa grossularia* on circalittoral rock and thin sands

These habitats are sandy sediments that may be covered in a layer of spent bivalve shells that supports a rich epifaunal community of barnacles and ascidians in addition to the infaunal element of the assemblage. The infauna is dominated by polychaetes such as *Mediomastus*, *Polycirrus* and *Lumbrineris* and some bivalves including *Mysella bidentata*.



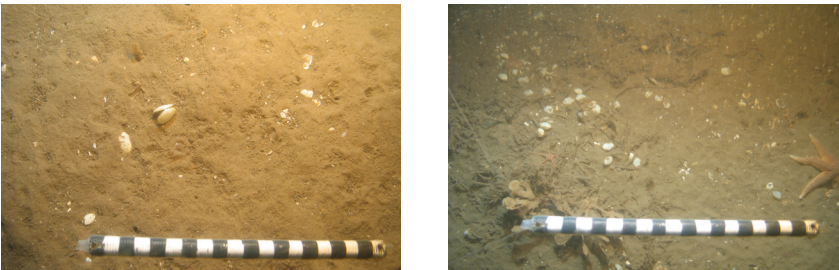
Seabed image of Station 95 and specimen images of *Balanus crenatus* and *Dendrodoa grossularia*.

(A4D.921) = CR.RTS.DRTS.RTS.PoBivAmp
Infaunal polychaetes with burrowing bivalves and amphipods in deep circalittoral thin sands

Stations 84, 85, 86, 87 & 88, all taken in Sole Pit, have been assigned to this Level 5 biotope, and a species specific Level 6 sub-biotope.

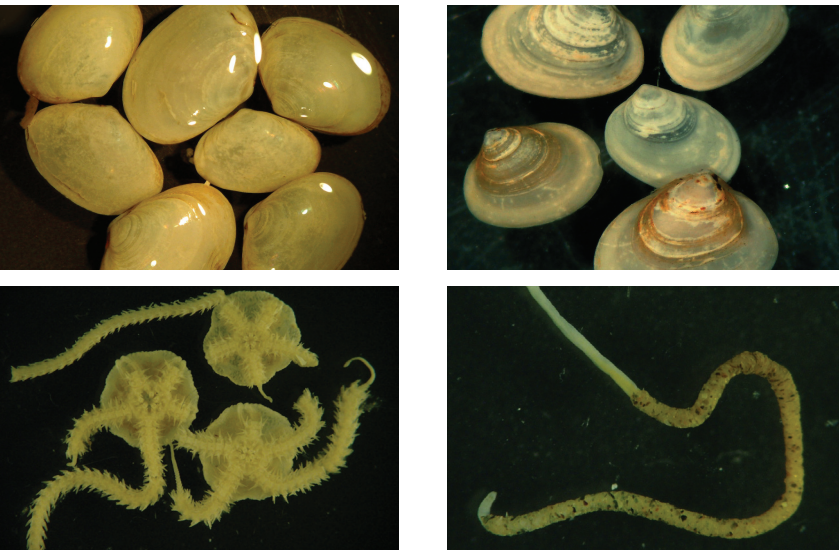
(A4D.9211) = CR.RTS.DRTS.RTS.AalbAfilMbid
Dense *Abra alba* with *Amphiura filiformis* and *Mysella bidentata* in deep circalittoral thin sands

The sediments in this area are generally fine grained, with occasional shells or gravels on the surface. However, video still images show that epifauna is very sparse with occasional hydroids visible.



Seabed images of Station 84 (top left) and Station 85 with spent bivalve shells (top right).

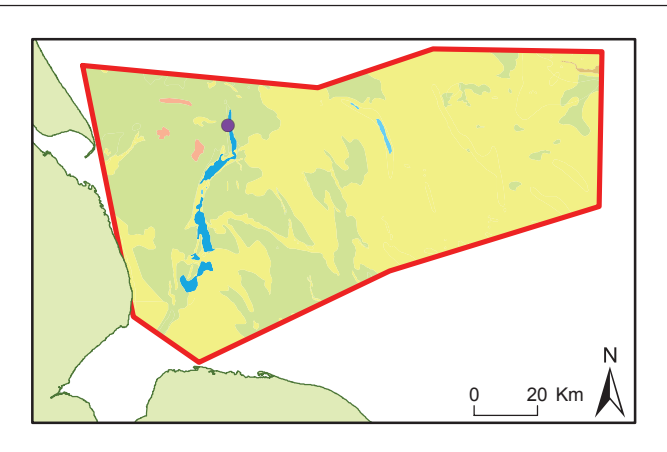
This sandy sediment supports high abundance of bivalves particularly *Abra alba* and *Mysella bidentata* and brittlestars especially *Amphiura filiformis* although *Ophiura* spp. and *Ophiothrix fragilis* are also present and may be locally abundant. Infaunal polychaete include *Anobothrus* spp., *Notomastus*, *Mediomastus* and *Galathowenia*.



Specimen images of *Abra alba*, *Mysella bidentata*, *Amphiura filiformis* and *Galathowenia* sp. (© seasurvey.co.uk).

(A4D.94)
Moderate energy, deep circalittoral rock and thin mixed sediment

This biotope complex was found at Station 17 only.



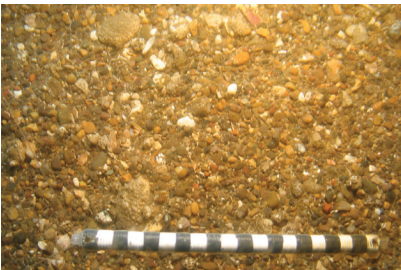
Location of stations within the EUNIS A4D.94 biotope complex, in relation to seabed character.

(A4D.942) = CR.RTS.BAscPo
Barnacles, ascidians and tube worms on circalittoral rock and thin mixed sediment

This biotope is a faunal assemblage found on different sediment types and so is functionally similar to A4D.922.

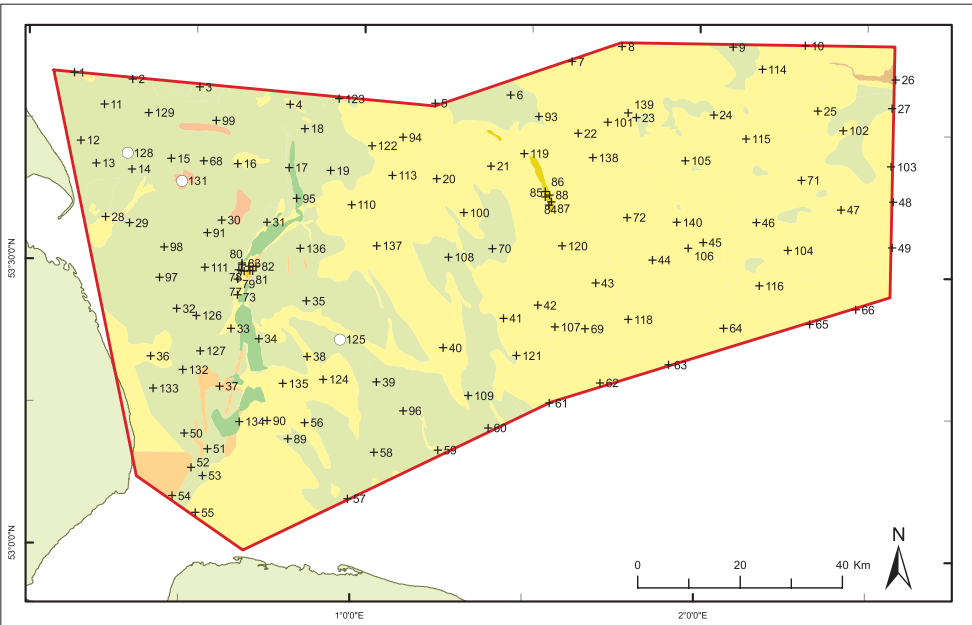
(A4D.9421) = CR.RTS.BcreCdunDgro
Balanus crenatus, *Chone duner* and *Dendrodoa grossularia* on circalittoral rock and thin mixed sediment

The gravels and pebbles provide attachment for a high abundance of encrusting fauna including barnacles and ascidians whilst supporting an infaunal community in the finer infaunal sediments. This sub-biotope is characterized by the encrusting *Balanus crenatus* and *Dendrodoa grossularia* and the infaunal polychaete *Chone duner*.

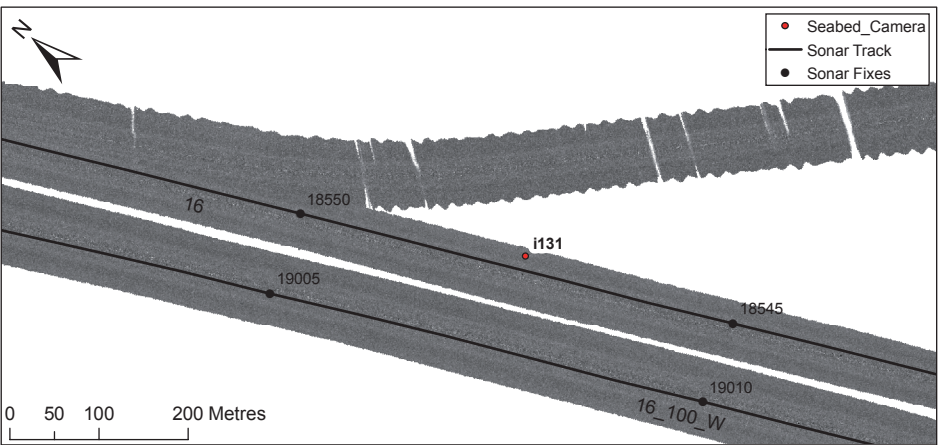


Seabed images of Station 17.

A5.1 —Sublittoral Coarse Sediment (SS.SCS)



Location of stations assigned to the EUNIS Level 3 Habitat A5.1 (white circles), in relation to seabed character.



Multibeam echo sounder (backscatter).

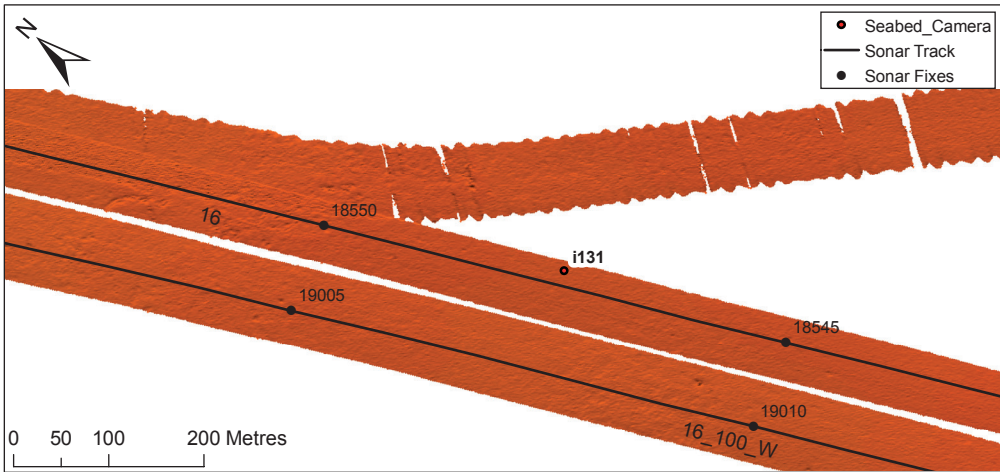
Solid Geology

In both samples, the solid geology is characterized by Cretaceous chalk overlain by the Bolders Bank Formation. Chalk is a fine-grained limestone. The Bolders Bank Formation is a boulder clay, and is considered 'rock' with respect to biota.

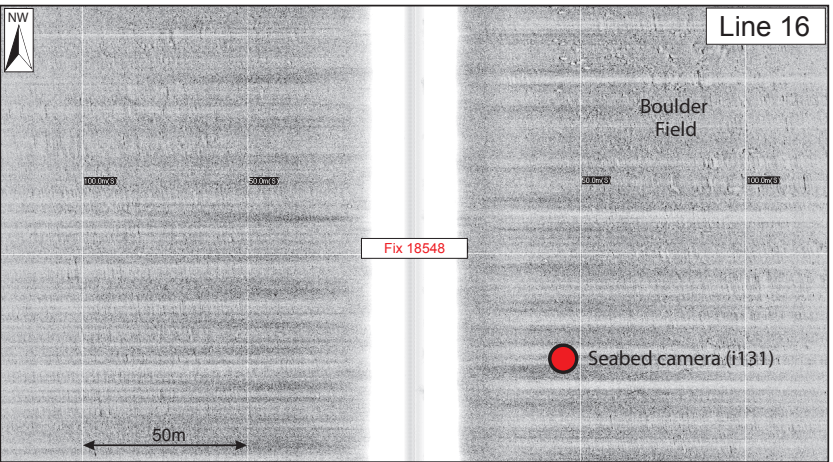
Superficial Sediment

Coarse sediments are dominant at the seabed, regionally mapped as gravel (131) or sandy gravel (128 and 125). Cobbles are common at

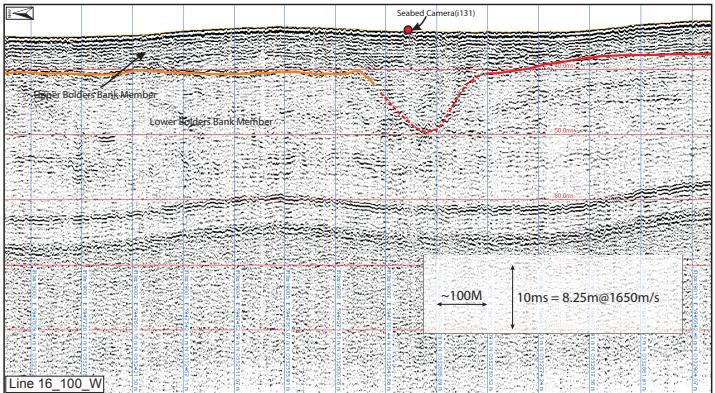
both stations 131 and 128, and boulders are present near sample 131 (see sidescan sonar figure to right). Neither the chalk, or Bolders Bank boulder clay are expected to be exposed at the seabed, but the seabed sediments are comprised of a pavement of coarse sediments derived from the Bolders Bank Formation. The boulder clay is inclusive of coarser sediments (gravel — boulders), whose composition represents the variety of lithologies found across eastern England, and southeastern Scotland, however flint from the chalk, and sandstone and limestone from the Cheviots of northeastern England are most common.



Multibeam echo sounder (bathymetry).



Sidescan sonar (backscatter) Sidescan sonar (backscatter).



Seismic section.

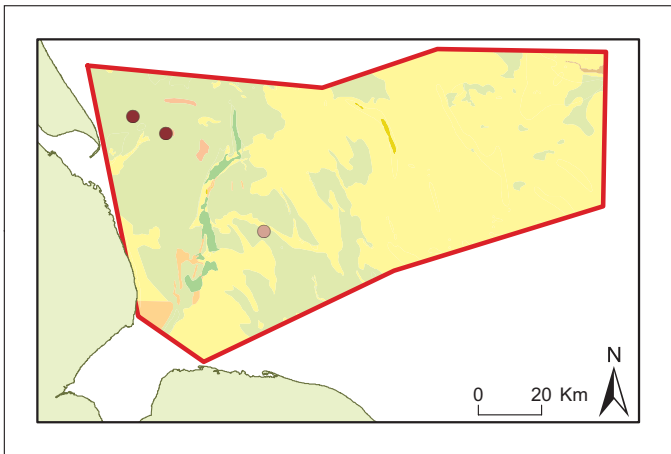
A5.1 — Sublittoral Coarse Sediment (SS.SCS)

Level 4 (Biotope Complex)

Level 5 (Biotope)

Level 5 (Biotope)

A5.14 = SS.SCS.CCS
Circalittoral coarse sediment



Location of stations within the EUNIS A5.14 biotope complex, in relation to seabed character. Brown = A5.14(8), pink = A5.14(9).

This is an uncommon biotope complex in the Humber REC study area, being found at only three sampling stations (Stations 125, 128 & 131). These stations are within a wider area of mixed sediments found in the western section of the Humber REC. The presence of large pebbles and cobbles are responsible for the coarse sediment category.

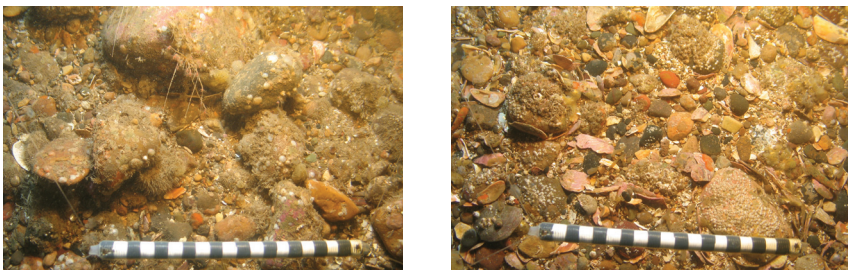
EUNIS describes this biotope complex as 'Moderately exposed habitats with coarse sand, gravelly sand, shingle and gravel in the infralittoral, are subject to disturbance by tidal streams and wave action. Such habitats found on the open coast or in tide-swept marine inlets are characterised by a robust fauna of infaunal polychaetes such as *Chaetozone setosa* and *Lanice conchilega*, cumacean crustacea such as *Iphinoe trispinosa* and *Diastylis bradyi*, and venerid bivalves. Habitats with the lancelet *Branchiostoma lanceolatum* may also occur'.

This biotope complex is widely distributed around the UK coastline with several records on the southern North Sea east coast (Figure 7.76).

The EUNIS Level 4 classification contains only seven Level 5 categories that do not cover the assemblages found at these stations and so 2 new biotopes A5.14(8) and A5.14(9) have been specified.

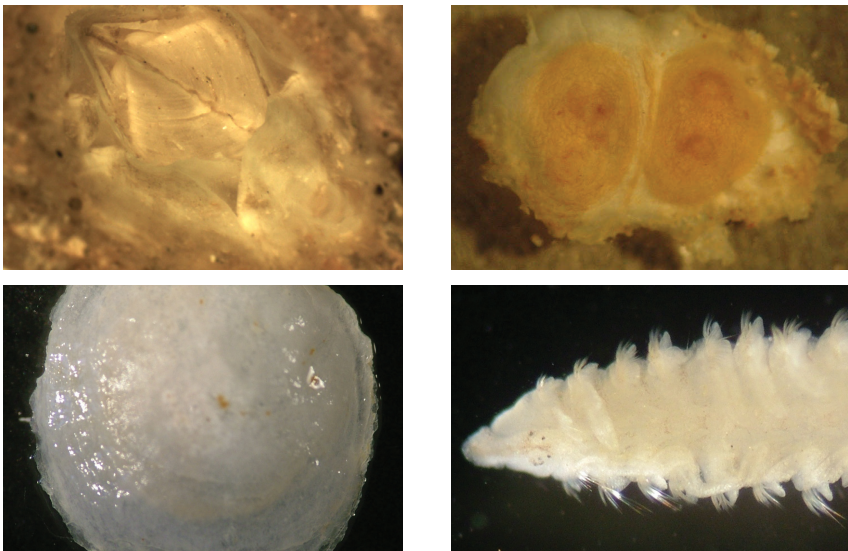
A5.14(8) = SS.SCS.CCS.BAscPo
Barnacles, ascidians and tube worms on circalittoral coarse sediment

This biotope was found at two stations (128 and 131) in the Humber REC area. The seabed images show a high abundance of encrusting fauna, particularly barnacles and ascidians, but also encrusting tube worms such as *Pomatoceros*, ascidians and saddle oysters (*Anomiidae*).



Seabed photos from Station 128 and Station 131 showing large pebbles and cobbles, covered in encrusting fauna, with smaller sediments in between.

The grab samples are dominated by the same groups of animals and there are particularly high abundances of the barnacle *Balanus crenatus* and ascidians including *Dendrodoa grossularia*. Other common epifauna includes Mytilidae and anomiidae. There are also several infaunal polychaete species including *Polycirrus*, *Mediomastus* and *Spio* spp. *Branchiostoma lanceolatum* was also present in high numbers at station 128.



Specimens of *Balanus crenatus* (top left), *Dendrodoa grossularia* (top right), saddle oyster *Anomiidae* (bottom left) and *Spio* sp. (bottom right). (© seasurvey.co.uk).

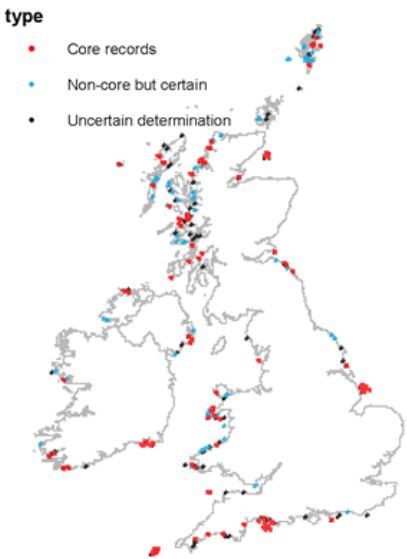
A5.14(9) = SS.SCS.CCS.SpF
Sparse fauna on circalittoral coarse sediments

This biotope of sparse fauna was found at Station 125 where there were only 57 animals collected in the grab sample. However, there is fairly high diversity considering the low abundance with 39 different taxa recorded. The seabed image shows fewer occurrences of encrusting fauna.



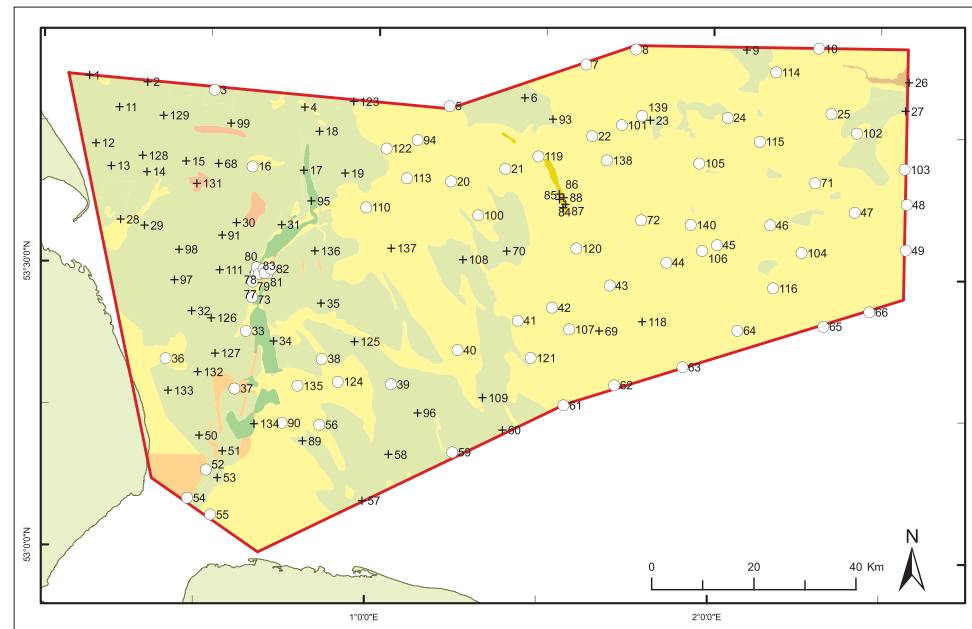
Seabed photos from Station 125 showing mixed sediments and specimen image of the infaunal polychaete *Spiophanes* sp.

The grab sample had low numbers of ascidians, barnacles and infaunal polychaetes such as *Spiophanes* sp.



Distribution map for A5.14 (Marine Habitat Classification code: SS. SCS.CCS) (Source: Connor *et al* 2004. Internet version, accessed 15/11/2010, © JNCC).

A5.2 — Sublittoral Sand (SS.SSa)



Location of stations assigned to the EUNIS Level 3 Habitat A5.2 (white circles), in relation to seabed character.



Sand waves.

Solid Geology

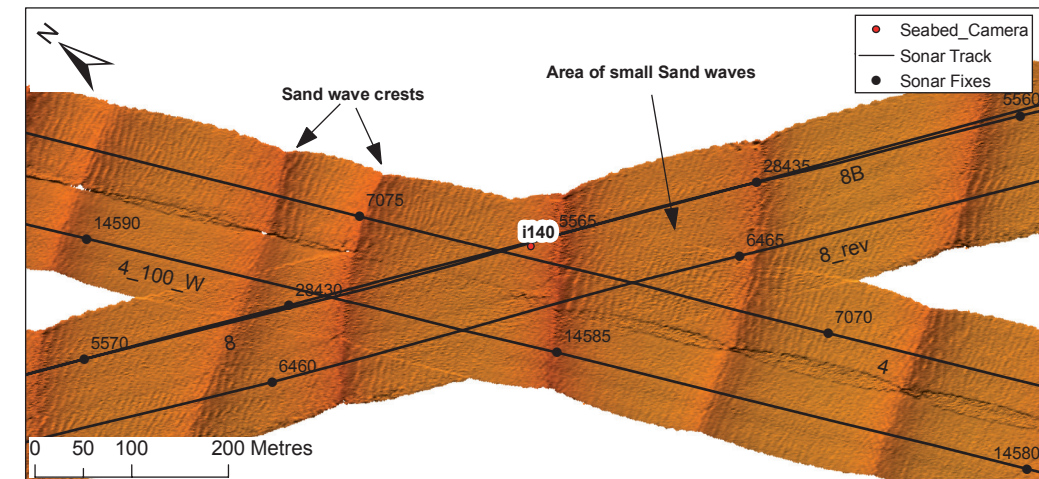
This biotope is found across the REC area and is inclusive of a variety of 'solid geology' settings. In keeping with the focus of the report, we will only discuss the geological units that are found at or near the seabed. This limits us to the chalk, which here is present underlying seabed sediments in the Silver Pit and the associated glacial outwash plain to the south, and the Sole Pit, however no samples of the A5.2 class are located within the Sole Pit. Chalk is a fine-grained limestone, which in the Silver Pit, dips to the west.

The remainder of the samples are of Holocene sediment of varying thickness which overlies the Bolders Bank Formation. The Bolders Bank Formation is a boulder clay, and is considered 'rock' with respect to biota.

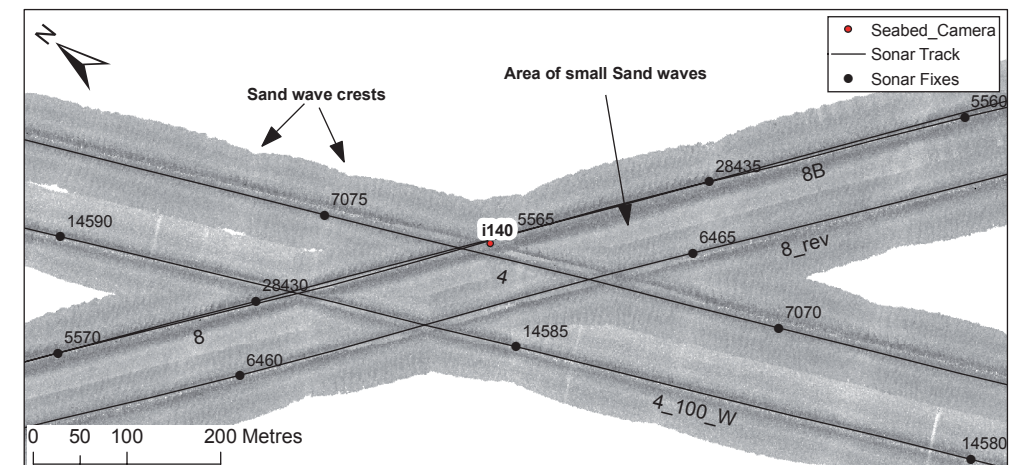
Superficial Sediment

The seabed sediment comprises sublittoral sand and is largely a reflection of the thickness of Holocene mobile sediment (sand, gravelly sand, and gravelly muddy sand) that overlies a gravelly pavement formed by the winnowing of fine material from the boulder clay of the Bolders Bank Formation. For these sample stations, the sand is sufficiently thick to cover the coarser-grained sediments which form a cover over the Bolders Bank formation. However, in the immediate vicinity of the stations it is possible that the sand only forms a thin veneer over the chalk or Bolders Bank Formation.

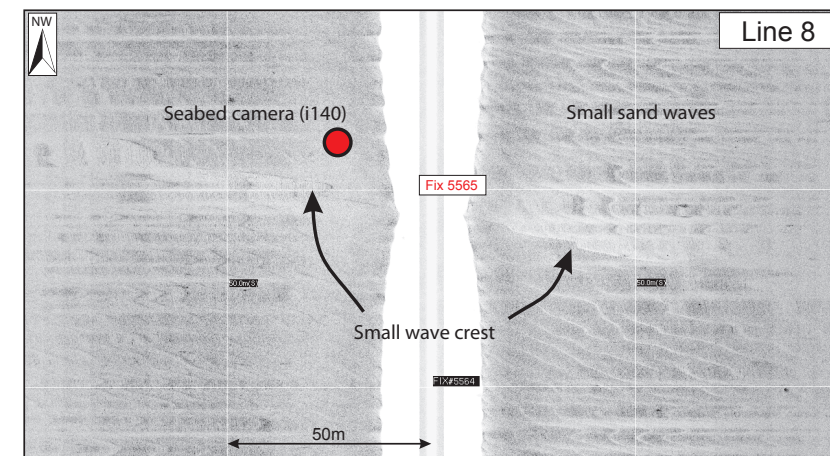
Much, but not all, of this sand is mobile, with sediment transport vectors varying across the site (Figure 2.4.3). But apart from in the west and southwest, these vectors have a predominant NNW azimuth. Stations may be located over a variety of bedforms from small-sand waves (see figures to the right), sand patches, sand ribbons, to sand banks which are 10's of metres thick and kilometres in length.



Multibeam swath corridor.



Multibeam echo sounder (backscatter).



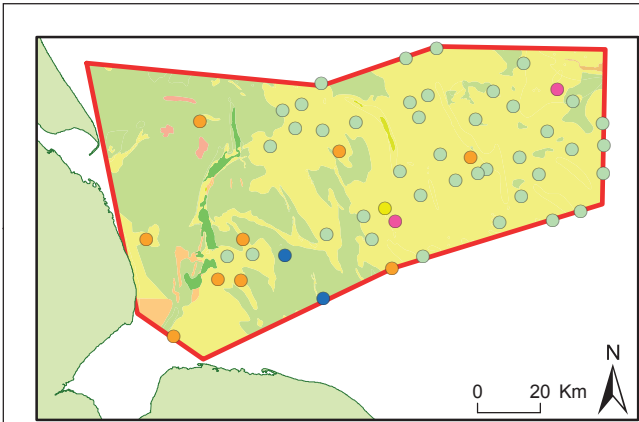
Sidescan sonar record.

A5.2 — Sublittoral Sand (SS.SSa)

Level 4 (Biotope Complex)

Level 5 (Biotope) & 6 (Sub-biotope)

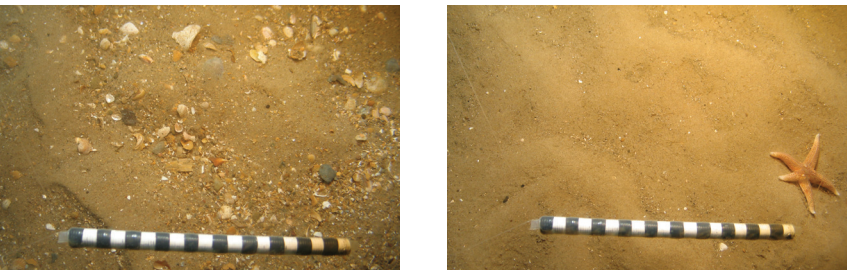
A5.25 = SS.SSa.CFiSa
Circalittoral fine sand



Location of stations assigned to the A5.25 biotope complex, in relation to seabed character with stations split to biotope and sub-biotopes: A5.25(41) light blue, A5.25(42) pink, A5.25(7) orange, A5.2551 yellow, A5.2552 dark blue.

This is a widespread biotope complex across the Humber REC study area, particularly in the east and south west corner. Patches of coarse sediment and shell fragments were observed but this was generally sparse and infrequent.

The EUNIS description for this biotope complex is: 'clean fine sands with less than 5% silt/clay in deeper water, either on the open coast or in tide-swept channels of marine inlets in depths of over 15–20 m. The habitat may also extend offshore and is characterised by a wide range of echinoderms (in some areas including the pea urchin *Echinocyamus pusillus*), polychaetes and bivalves. It is generally more stable than shallower, infralittoral sands and consequently supports a more diverse community.' Although this biotope complex has not been extensively recorded, it does not appear to be restricted to any particular part of the UK coast.



Seabed photos from Stations 5 (left), 62 (right).

A5.25(4) = SS.SSa.CFiSa.PoBivAmp

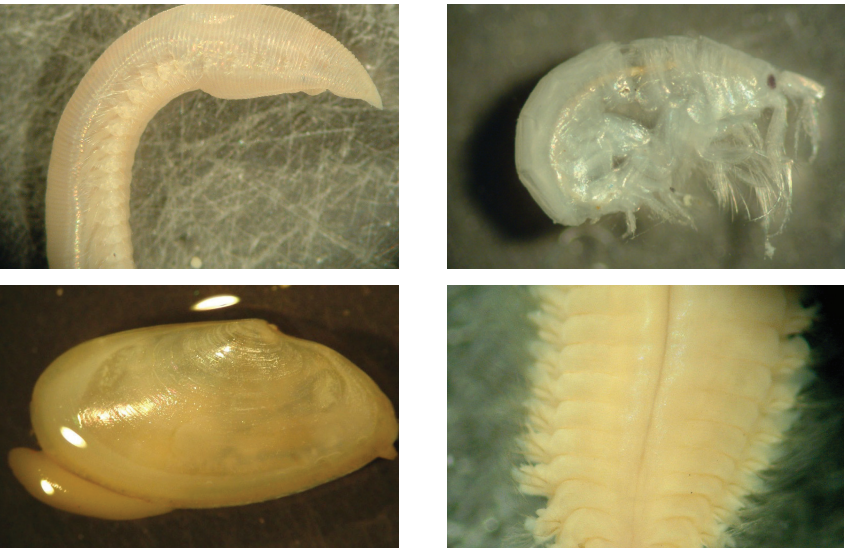
Infaunal polychaetes with burrowing bivalves and amphipods in circalittoral fine sand

The description of this biotope has been amended to reflect a more functional community type comprised primarily of polychaetes, bivalves and amphipods. This type of community has been recorded from the central and northern North Sea (Basford and Eleftheriou, 1989; Kunitzer *et al.* 1992; Heip & Craeymeersch, 1995). The species that may be found in this group vary, possibly due to slight differences in sediment size as well as more geographical differences, and this is reflected in the Level 6 sub-biotopes.

A5.25(41) = SS.SSa.CFiSa.ApriBelePo

Abra prismatica, *Bathyporeia elegans* and polychaetes in circalittoral fine sand

This is a very widespread sub-biotope that applies to 42 stations, mostly in the east of the study area (Figure 7.85). It is characterized by several species of infaunal polychaetes, particularly *Ophelia borealis* and *Nephtys*, the burrowing amphipod *Bathyporeia* and *Abra* spp. bivalves.

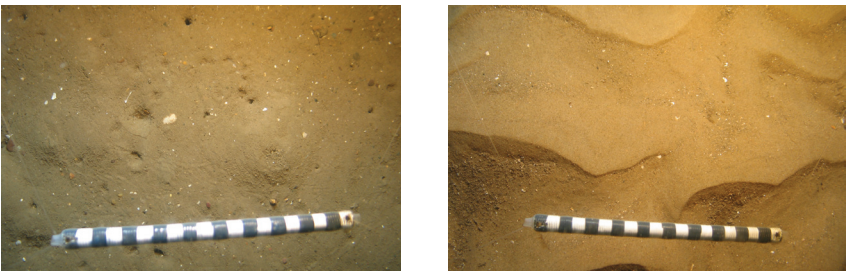


Specimen photos of *Ophelia borealis* (top left), *Bathyporeia* (top right), *Abra prismatica* (bottom left) and *Nephtys* spp. (bottom right). (© seasurvey.co.uk).

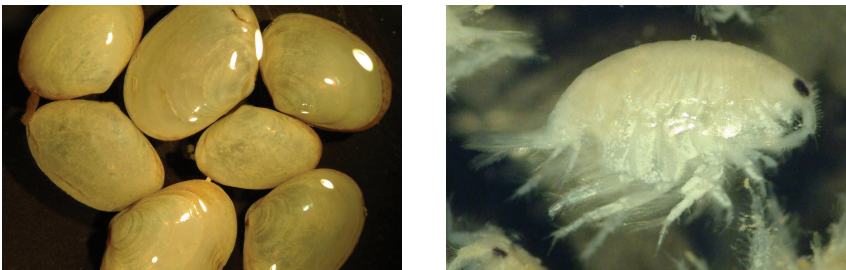
A5.25(42) = SS.SSa.CFiSa.AalbUelePo

Abra alba, *Urothoe elegans* and polychaetes in circalittoral fine sand

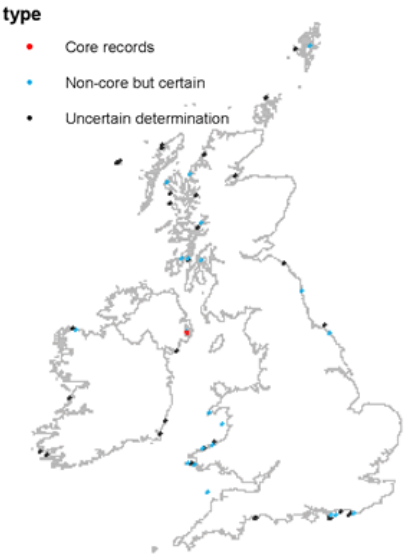
This new sub-biotope has been generated to account for variation in the species composition of the biotope A5.25(4). This variant is found at two stations (25 and 107) in the east of the study area.



Seabed photos from Stations 25 (left), 107 (right) showing sandy sediments with and without burrow/tube holes on the surface.



Specimen photos of *Abra alba* (left) and *Urothoe* spp. (bottom right). (© seasurvey.co.uk).



Distribution map for A5.25 (Marine Habitat Classification code: SS.SSa.CFiSa)
(Source: Connor *et al* 2004. Internet version, accessed 11/11/2010, © JNCC).

A5.2 — Sublittoral Sand (SS.SSa)

Level 5 (Biotope)

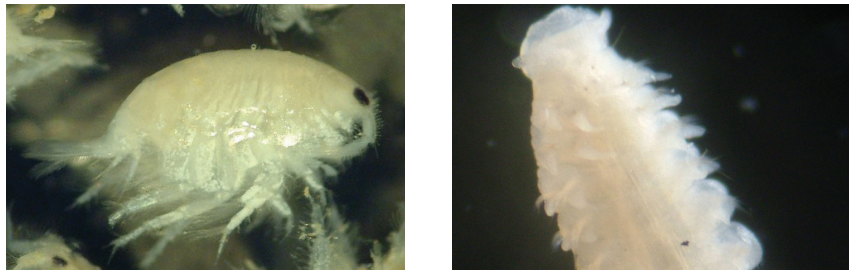
Level 5 (Biotope) & 6 (Sub-biotope)

A5.25(5) = SS.Ssa.CfiSa.BAscPo
Barnacles, ascidians and tube worms on circalittoral fine sand

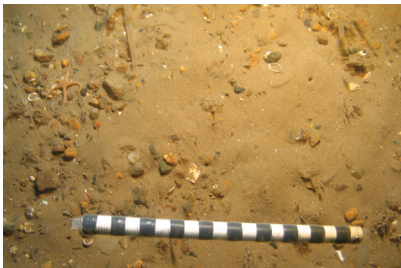
This new Level 5 biotope, which was also found on the south coast of the UK (see James, *et al.* 2010), has been created to reflect the presence of high abundance of epifaunal species in a predominantly sandy habitat. This biotope occurs where there are gravels or shell fragments present, such as at the base of sandwaves.

A5.25(51) = SS.Ssa.CfiSa.BaAscTw.BcrePlamUele
Balanus crenatus, *Pomatoceros lamarki* and *Urothoe elegans* in circalittoral fine sand

This particular combination of species was only found at Station 42, in the middle of the study area. It is dominated by the burrowing amphipod *Urothoe*, the bivalve *Abra alba* and the polychaete *Spiophanes* spp.



Specimen photos of *Urothoe elegans* (left) and *Spiophanes bombyx* (right).
(© seasurvey.co.uk).



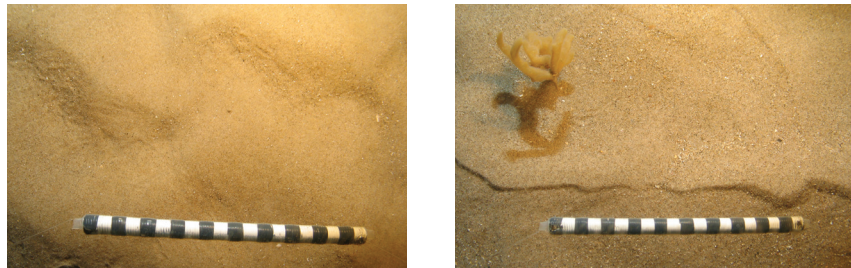
Seabed photos for A5.25(51) at Station.

A5.25(52) = SS.SSa.CFiSa.DgroPlamBa
Dendrodoa grossularia, *Pomatoceros lamarki* and barnacles on circalittoral fine sand

This variant is found at two stations (39 and 59) in the east of the study area and is distinguished from A5.25(41) by the presence of *Abra alba* and the amphipods *Urothoe elegans* and *Bathyporeia*. The characterising polychaetes are *Spiophanes bombyx* and *Notomastus* whilst *Ophelia borealis* and the tube building family Pectinariidae may also be present in high abundance.

A5.25(7) = SS.SSa.CfiSa.SpF
Sparse fauna in circalittoral fine sand

This new Level 5 biotope has been created to reflect those areas where there is sparse fauna in fine clean sandy sediments. This biotope was assigned to seven stations in areas of sandy sediments where the fauna was particularly sparse. The average abundance per grab sample in this group was 10 individuals. The species present may be similar to those observed in biotope A5.25(4), particularly *Ophelia borealis* and *Glycera* spp. but also present are occasional amphipods such as *Urothoe* and the bivalve *Goodalia*.



Seabed photos from Stations 61 (left) and Station 100 with the bryozoan *Alcyonidium diaphanum* visible.

Epifauna was rarely observed in this group, except for the occasional presence of the bryozoans *Flustra foliacea* and *Alcyonidium diaphanum* attached to coarse particles beneath the surface of the sand.

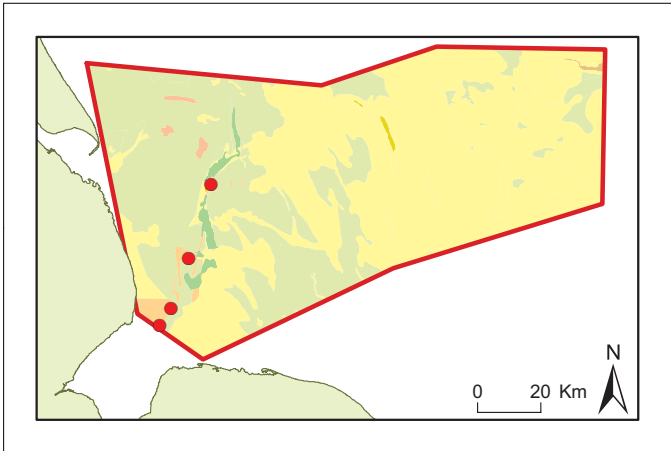


Specimen photos of *Ophelia borealis* (left), and *Glycera* (right). (© seasurvey.co.uk).

A5.2 — Sublittoral Sand (SS.SSa)

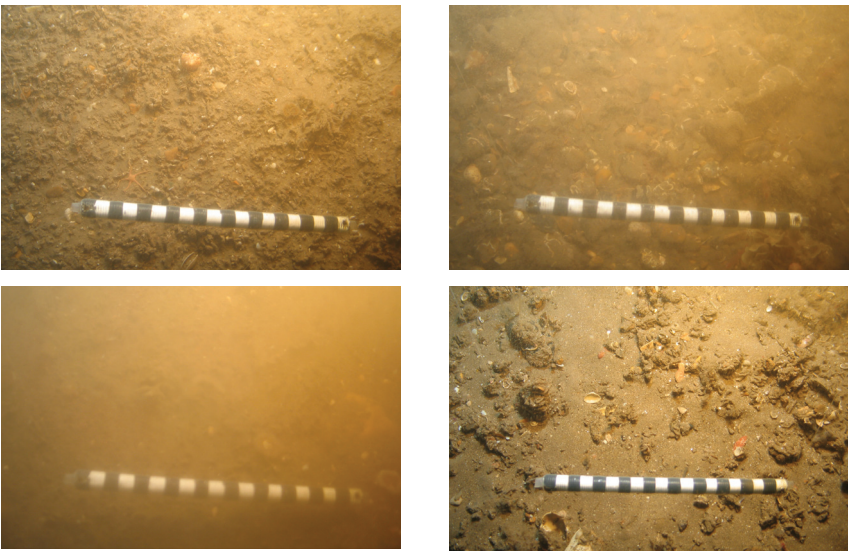
Level 4 (Biotope Complex)

A5.26 = SS.SSa.CMuSa
Infralittoral muddy sand



Location of stations assigned to the A5.26 biotope complex, in relation to seabed character.

This is a relatively uncommon biotope complex in the Humber REC study area, with only four stations in the western section. At some stations there is a layer of spent bivalve shells on the surface of the sediment and occasional patches of gravel. Stills images are often cloudy indicating the presence of fine particulate matter.



Seabed photos from Stations 37 (top left), 52 (top right), 54 (bottom left) and 82 (bottom right).

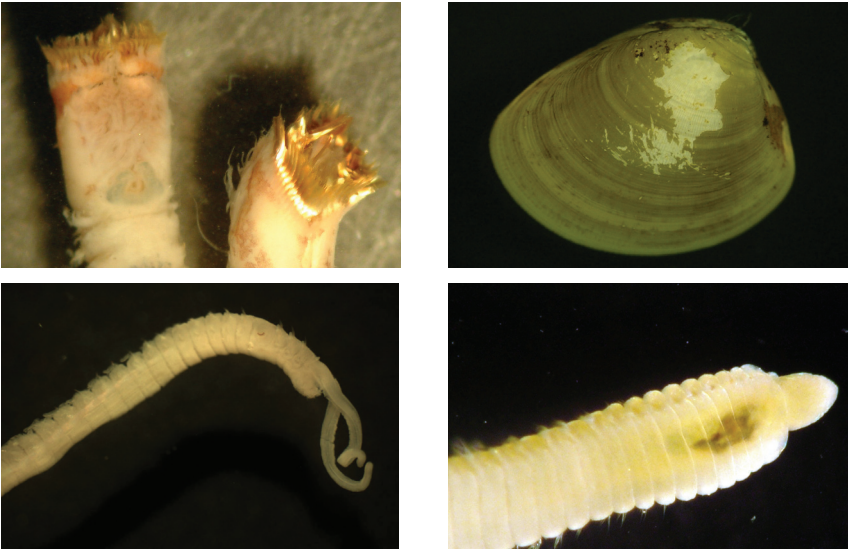
There was sparse epibenthic megafauna observed on the video with occasional crabs, such as *Liocarcinus* spp., burrowing anemones and fairly frequent occurrences of the brittle star *Ophiura*. *Sabellaria* tubes covered the seabed surface in many areas and where larger sediments on shells were present hydroids, bryozoans and the encrusting tube worm *Pomatoceros* were observed.



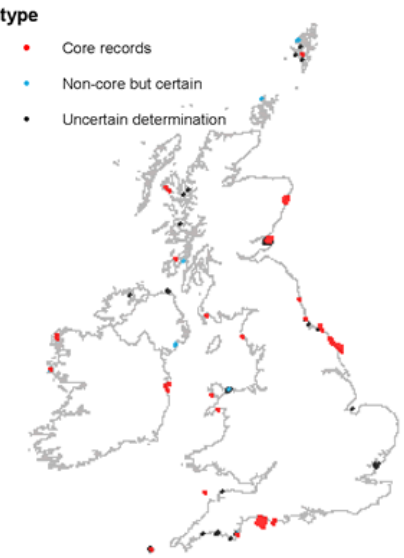
Epifauna: *Liocarcinus* spp. (left), *Ophiura* spp. (© seasurvey.co.uk).

In grab samples, the sand tube dwelling *Sabellaria spinulosa* was the most characteristic species being present in all samples and often in very high abundance. Other characteristic fauna are the bivalve *Nucula*, several species of infaunal polychaete including *Polydora*, *Lumbrineris* and *Mediomastus*. Occasionally the encrusting tube worm *Pomatoceros* spp. and the amphipod *Ampelisca* were found in very high abundance but these species are not characteristic of the group. Where these species do occur they are often in high abundance. *Pomatoceros* settles preferentially where adults are already present and *Ampelisca* form nests that may contain several hundred individuals. At a few stations where sediments large enough for attachment were present there were high numbers of encrusting organisms such as barnacles and Surpulid tube worms although these are not generally characteristic of this habitat type.

The Marine Habitat Classification for Britain and Ireland (MHCBI) distribution map for this biotope complex shows that it has been identified on most coasts around Britain and Ireland albeit in fairly low numbers.



Specimen photos of *Sabellaria spinulosa* (top left), *Nucula* (top right), *Polydora* (bottom left) and *Lumbrineris* (bottom right). (© seasurvey.co.uk).



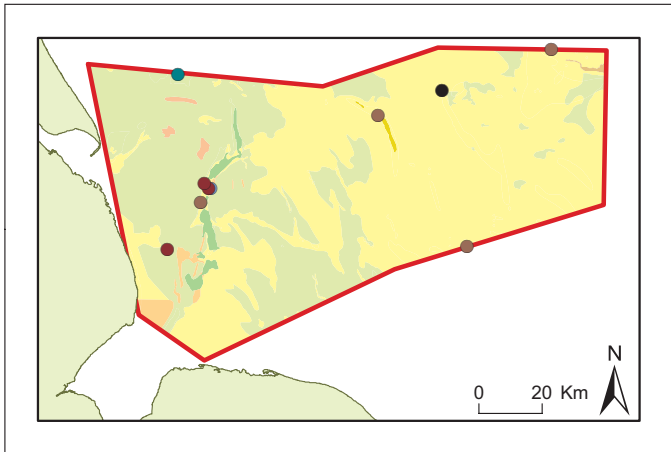
Distribution map for A5.26 (Marine Habitat Classification code: SS.SSa.CMuSa)
(Source: Connor et al 2004. Internet version, accessed 11/11/2010, © JNCC).

A5.2 — Sublittoral Sand (SS.SSa)

Level 4 (Biotope Complex)

A5.27 = SS.Ssa.OSa

Deep circalittoral Sand



Location of stations assigned under the A5.27 biotope complex, in relation to seabed character. Level 6 sub-biotopes are A5.2741 (brown), A5.2742 (black), A5.2751 (green) and A5.2752 (blue).

This is a relatively uncommon biotope complex in the Humber REC study area, with seven stations distributed throughout the area. All were assigned to higher Level 6 biotopes. These biotopes are similar to those in circalittoral sand in shallower waters.

EUNIS describes this biotope complex as 'Offshore (deep) circalittoral habitats with fine sands or non-cohesive muddy sands. Very little data is available on these habitats however they are likely to be more stable than their shallower counterparts and characterised by a diverse range of polychaetes, amphipods, bivalves and echinoderms'.



Distribution map A5.27 = SS.Ssa.OSa (Source: Connor *et al* 2004. Internet version, accessed 15/11/2010, © JNCC).

Level 5 (Biotope) & Level 6 (Sub-biotope)

A5.27(4) = SS.Ssa.OSa.PoBivAmp

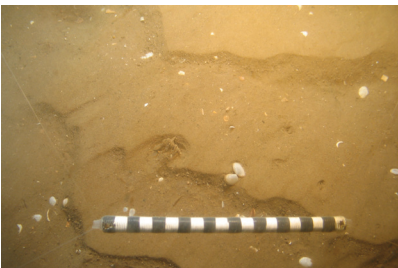
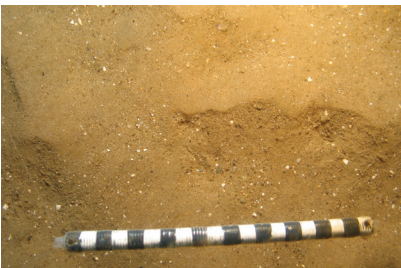
Infaunal polychaetes with burrowing bivalves and amphipods in deep circalittoral sand

This biotope was found at 5 stations, assigned to two Level 6 sub-biotopes.

A5.27(41) = SS.Ssa.OSa.ApriBelePo

Abra prismatica, *Bathyporeia elegans* and polychaetes in deep circalittoral sand

This sub-biotope was found at four stations, characterized by the presence, and high abundance, of *Abra*, the polychaetes *Ophelia borealis* and *Notomastus* and the presence of the amphipod *Bathyporei*. The brittle star *Ophiura* spp. may also be observed on the surface. Seabed images showed clean, rippled sand, sometimes with empty *Abra* shells.



Seabed photos from Stations 10 (left) and 119 (right).



Specimen photographs of *Abra alba* (left) and *Notomastus* (right). (© seasurvey.co.uk).

A5.27(42) = SS.Ssa.OSa. AalbUelePo

Abra alba, *Urothoe elegans* and polychaetes in deep circalittoral sand

This sub-biotope was only found at station 139, where there was a high abundance of *Abra alba* and several polychaete species.

Level 5 (Biotope) & Level 6 (Sub-biotope)

A5.27(5) = SS.Ssa.OSa.BaAscPo

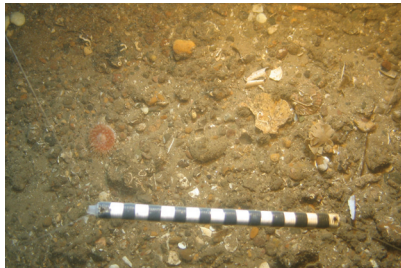
Barnacles, ascidians and tube worms on deep circalittoral sand

This biotope was found at two stations, 3 and 76, each of which are assigned to Level 6 sub-biotopes.

A5.27(51) = SS.Ssa.OSa.BcreCdunDgro

Balanus crenatus, *Chone duneri* and *Dendrodoa grossularia* on deep circalittoral sand

The seabed image of Station 3 shows a layer of coarse sediment, providing attachment for a number of encrusting species, on the surface of the sand. The sand supports a diverse range of infaunal polychaetes including *Mediomastus*, *Polynoidae* and *Chone duneri*.



Seabed image of Station 3 and the polychaete worm *Chone duneri* (© seasurvey.co.uk).

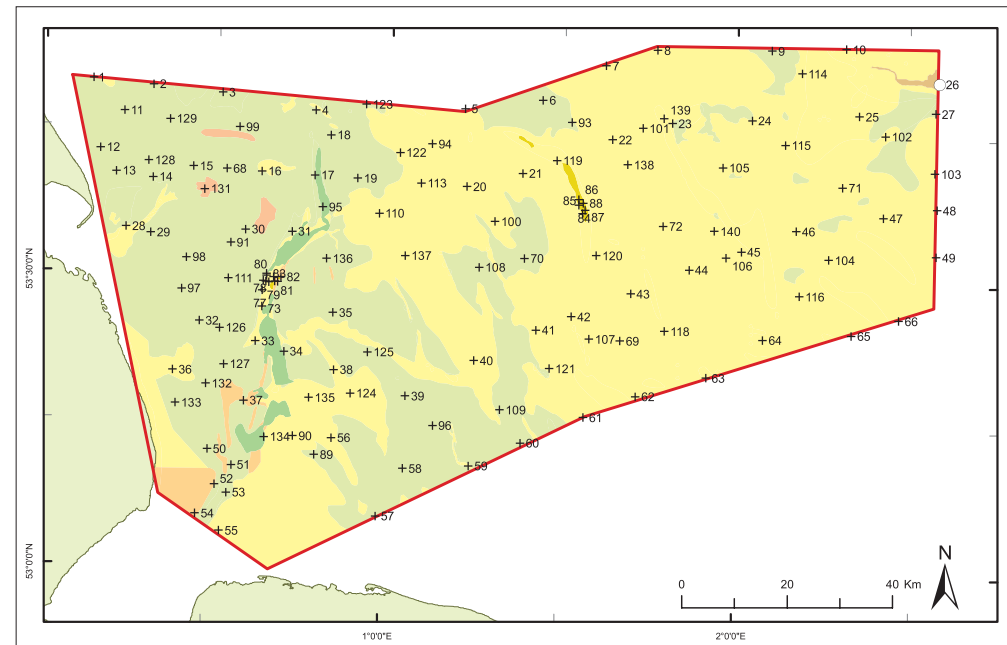
A5.27(52) = SS.Ssa.OSa.BcrePlamUele

Balanus crenatus, *Pomatoceros lamarki* and *Urothoe elegans* in deep circalittoral sand

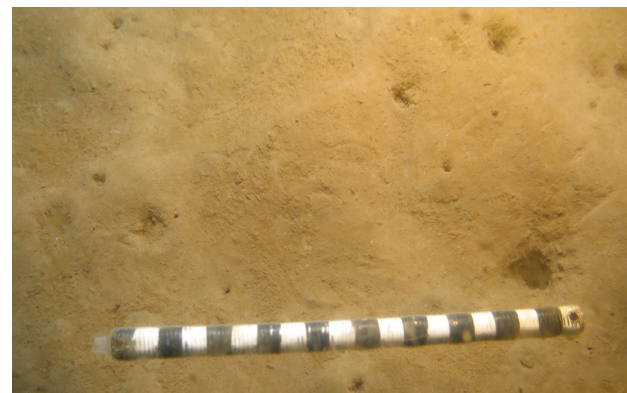


Seabed image of Station 76 showing coarse particles on the surface of sandy sediments and the burrowing amphipod *Urothoe* spp. (© seasurvey.co.uk).

A5.3 — Sublittoral Mud (SS.SMu)



Location of stations assigned to the EUNIS Level 3 Habitat A5.3 (white circles), in relation to seabed character.



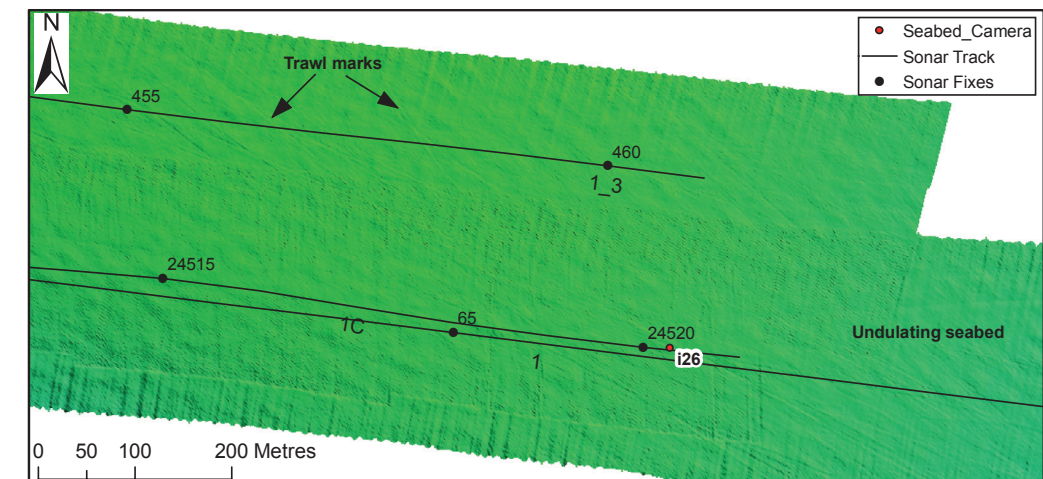
Seabed camera (i26).

Solid Geology

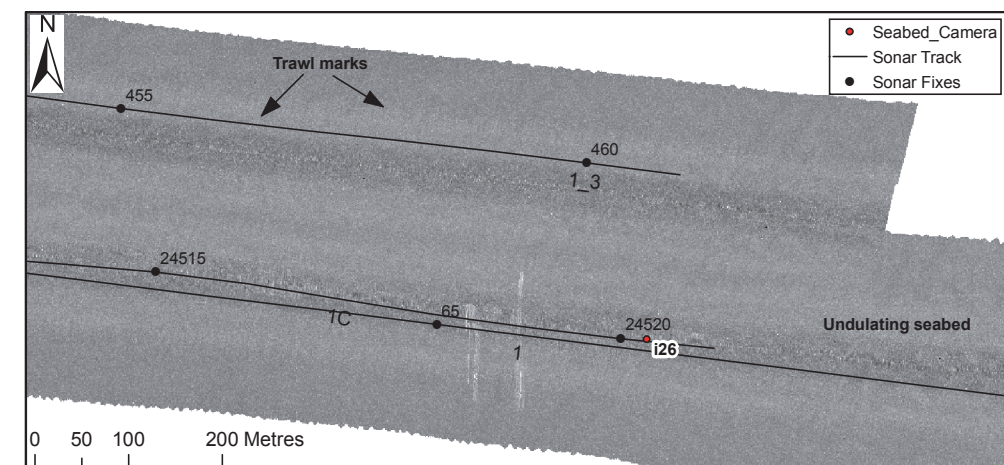
There is no solid, or hard sediment or rock immediately underlying the Holocene sediments of the one sample station which is representative of sublittoral mud. The seabed sediments are underlain by the Botney Cut Formation, which comprises soft clays and intercalated fine-grained sand which is of a shallow marine origin. The Botney Cut Formation typically infills incised channels into the Bolders Bank formation. While the Botney Cut Formation muds are soft, they are expected to support biogenic burrowing.

Superficial Sediments

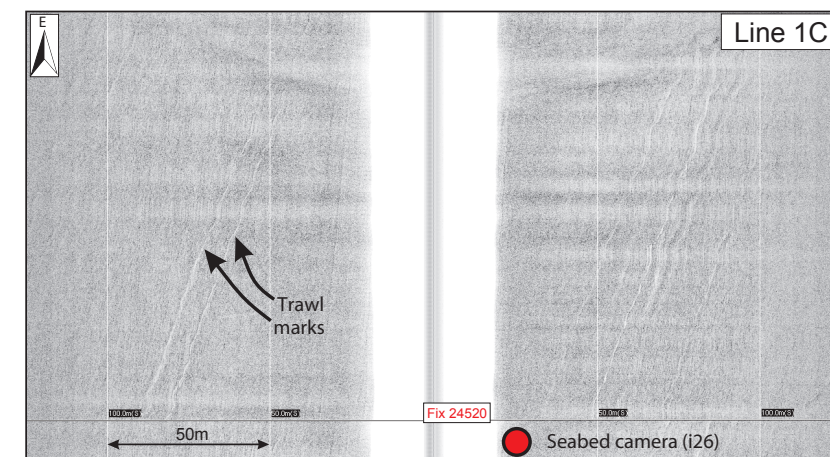
The muddy sand found in this most northeast corner of the REC area is probably derived from the underlying Botney Cut Formation, but may also be a reflection of the very low-amplitude bottom currents in the area. The sample station is located within the Markham's Hole, a tunnel valley or Deep of smaller dimensions than those of the Silver and Sole pits. The hummocky seabed is expected to be a sedimentary bedform though may be of glacial origin. Photographs clearly show the seabed to be soft enough for burrowing, yet firm enough to maintain the structures.



Multibeam echo sounder (bathymetry).



Multibeam echo sounder (backscatter).



Sidescan sonar (backscatter)

A5.3 — Sublittoral Mud (SS.SMu)

Level 4 (Biotope Complex)

Level 5 (Biotope) & Level 6 (Sub-biotope)

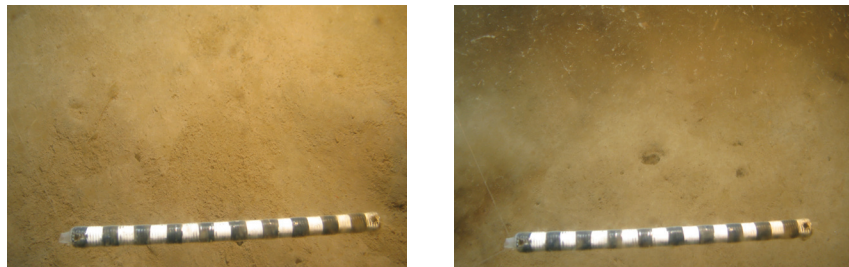
A5.37 = SS.SMu.Omu
Deep circalittoral mud

This is an uncommon biotope complex in the Humber REC study area and was assigned to Station 26 only. This sample is in the north east corner of the survey area where there Markham's Hole tunnel valley is located. As the seabed images indicate the sediments are very fine and peppered with faunal burrow holes.

EUNIS describe this biotope complex as follows: 'In mud and cohesive sandy mud in the offshore circalittoral zone, typically below 50-70 m, a variety of faunal communities may develop, depending upon the level of silt/clay and organic matter in the sediment. Communities are typically dominated by polychaetes but often with high numbers of bivalves such as *Thyasira* spp., echinoderms and foraminifera'.

Station 26 is in 60 m of water, at the edge of Markham's Hole.

The seabed images show this station has fine muddy sediments characterized by a number of burrow holes which probably belong to a mixture of crustaceans and polychaetes.



Seabed photos from Station 26 showing muddy sediments and burrow holes.

This biotope has been further categorized by functional group (EUNIS Level 5 biotope) and species specific group as detailed below.

A5.37(9) = SS.SMu.Omu.PoBiAmp
Infaunal polychaetes with burrowing bivalves and amphipods in deep circalittoral mud

This assemblage is numerically and taxonomically dominated by bivalves and polychaetes and amphipods are also present.

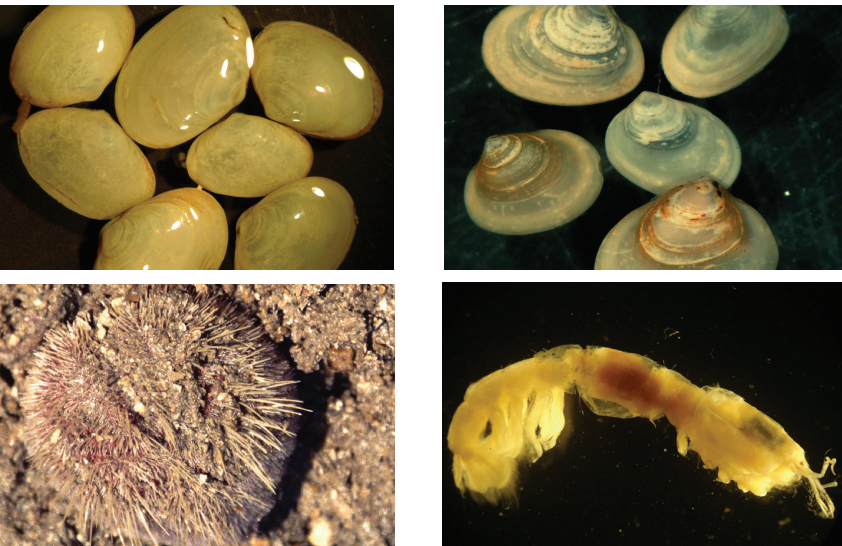
A5.37(91) = SS.SMu.Omu.LkorAfilBiv
Lagis koreni and *Amphiura filiformis* with bivalves in deep circalittoral mud

The faunal assemblage at station 26 is typical of this sediment type with a range of infaunal animals. It was numerically dominated by the bivalves *Myssella bidentata* and *Abra alba*, *Corbula gibba* and *Nucula nitidosa* were also found.

The most common polychaete group was the Pectinariidae, including *Lagis koreni*, a group of worms that construct a highly regular tapered tube that can often be seen protruding from the sediment surface.

Several echinoderm species, including the brittle star *Amphiura filiformis* and the burrowing heart urchin *Echinocardium cordatum*, both of which burrow in muddy and sandy sediments, are found in this assemblage.

The burrowing mud shrimp *Callinassa subterranea* was also present, a species which creates the characteristic burrow holes in the sediment visible in the seabed images.

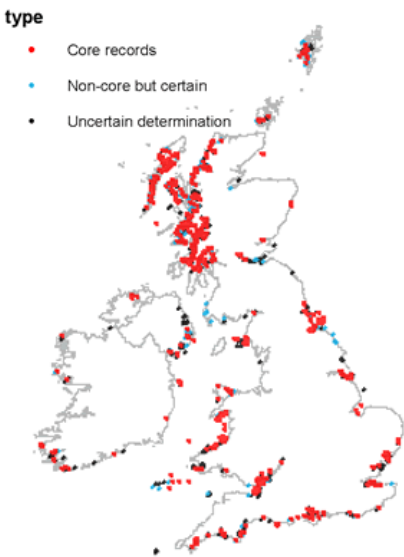


Characteristic faunal of sub-biotope A5.37(91); *Abra alba*, *Myssella bidentata*, *Echinocardium cordatum* and the burrowing shrimp *Callinassa subterranea* (© seasurvey.co.uk).



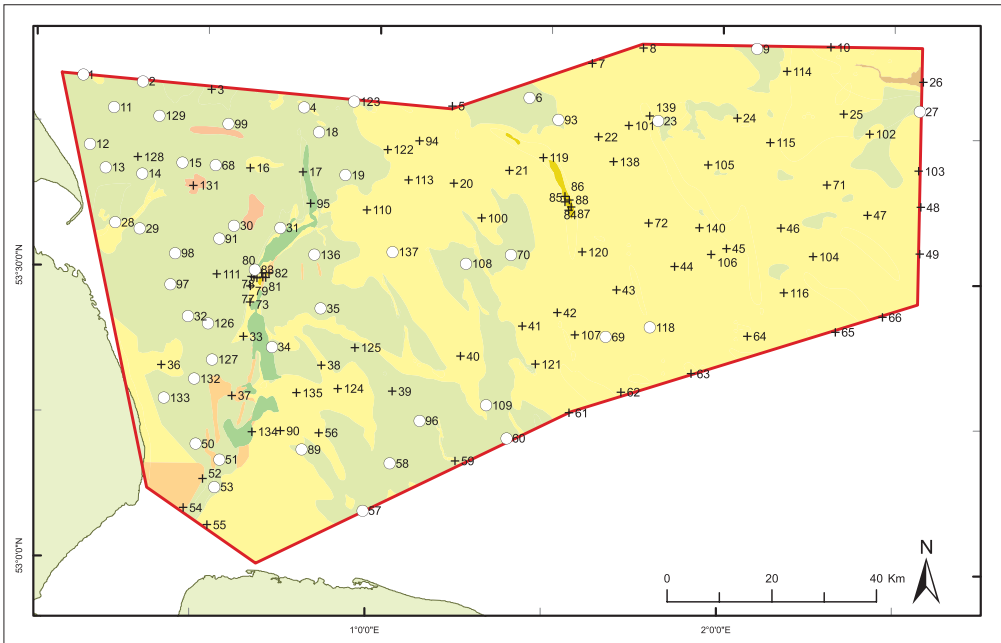
Specimen photographs to show *Lagis koreni* and the sandy tubes this species constructs. (© seasurvey.co.uk).

This biotope complex is widely distributed around all coasts of the UK.

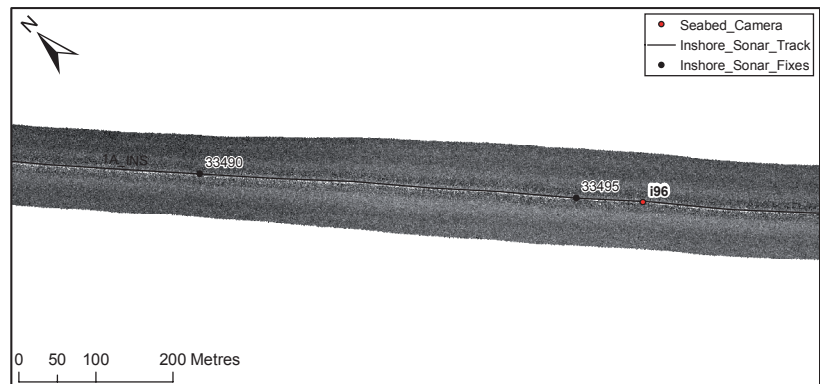


Distribution map for A5.3 (Marine Habitat Classification code: SS. SCS.CCS)
(Source: Connor et al 2004. Internet version, accessed 16/11/2010, © JNCC).

A5.4 — Sublittoral mixed sediment (SS.SMx)



Location of stations assigned to the EUNIS Level 3 Habitat A5.4 (white circles), in relation to seabed character.



Multibeam echo sounder (backscatter).

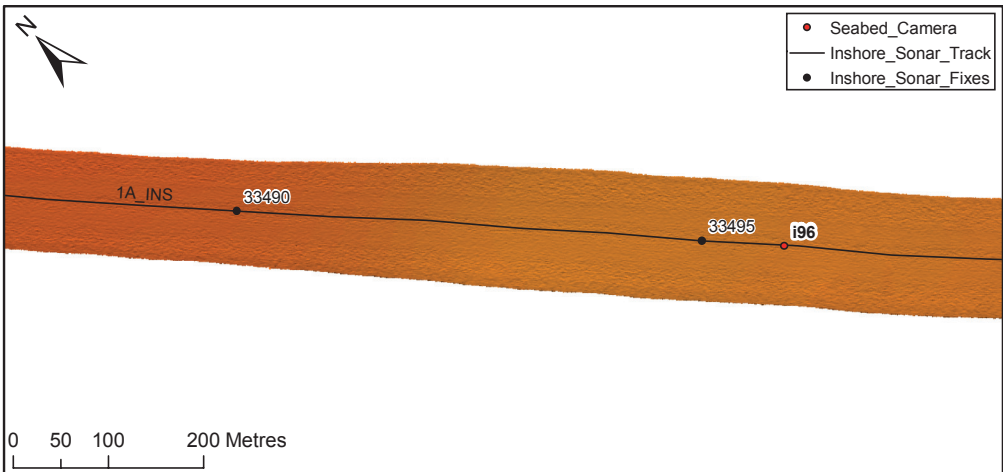
Solid Geology

Like the sublittoral sand, the sublittoral mixed sediments are dispersed across the whole of the REC area, inclusive of a variety of 'solid geology' settings, from Cretaceous, limestone chalk, to the glacial till of the Bolders Bank Formation, and the soft clays of the Botney Cut Formation.

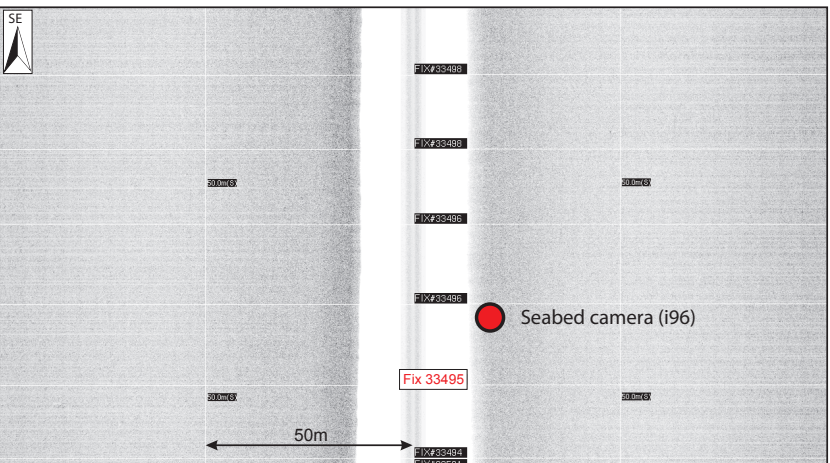
Superficial Sediment

As labeled, these sediments are of mixed lithology, potentially inclusive of mud, sand, or gravel, but with no dominant end member (Figure 4.2.7). The sediment type from the REC area which is most commonly classed as 'mixed' is sandy gravel, with lesser accumulations of muddy sandy

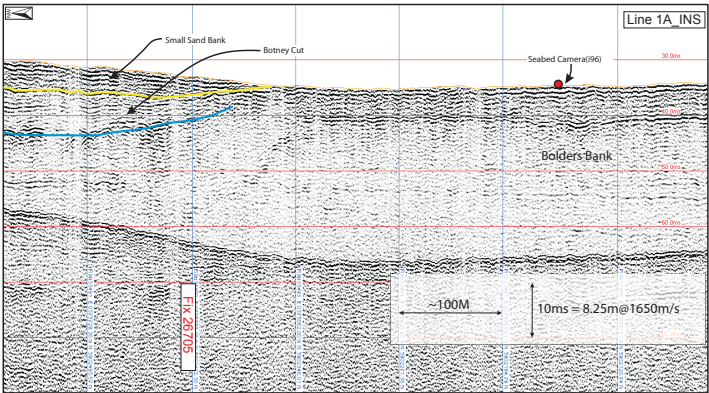
gravel. Like the distribution on the Folk maps of sandy gravel, the mixed sediments are concentrated in the west where coarser sediments are a result of stronger bottom currents. It may also be that initially there was a higher proportion of coarse-grained sediments present in the west, a consequence of the ice sheet transporting the coarse-grained material away from the coast sub-glacially. The distribution of 'mixed' sediments is necessarily a map of bulk (majority component) sediment content, and does not reflect local variation. Sand waves, and other bedforms associated with mobile sand will not be uncommon, as it is possible that there are exposures of chalk and the Bolders Bank Formation, particularly in areas where there is no geophysical and/or ground-truthing data.



Multibeam echo sounder (bathymetry).



Sidescan sonar (backscatter).

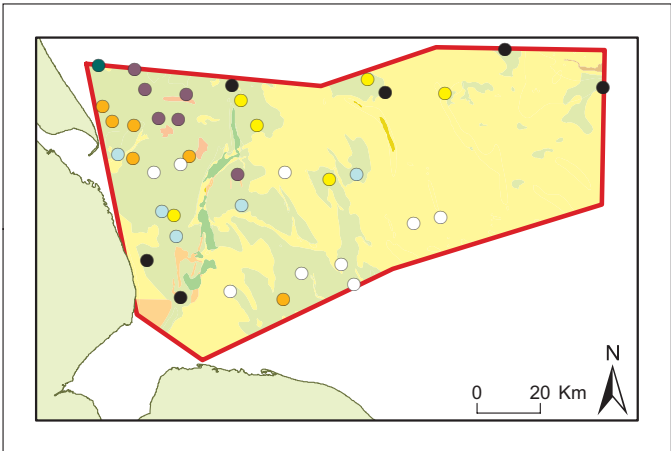


Seismic section.

A5.4 — Sublittoral mixed sediment (SS.SMx)

Level 4 (Biotope Complex)

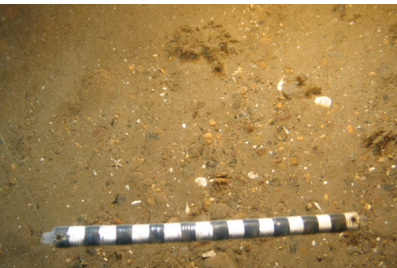
A5.44 = SS.SMx.CMx
Circalittoral mixed sediment



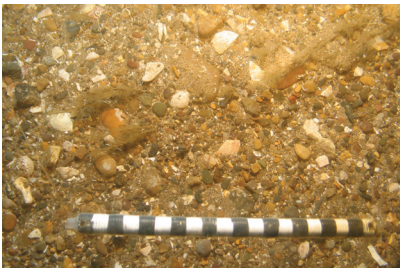
Location of stations within the EUNIS A5.44 biotope complex, in relation to seabed character. Circle colours: black = A5.44(71), yellow = A5.44(72), light blue = A5.44(A), green = A5.44(8), purple = A5.44(81), orange = A5.44(82), white = A5.44(83).

This biotope complex occurred primarily in the western half of the Humber REC study area. The sediments in this area typically comprised of sands with occasional gravels and pebbles.

EUNIS describes this biotope complex as 'Mixed (heterogeneous) sediment habitats in the circalittoral zone (generally below 15–20 m) including well mixed muddy gravelly sands or very poorly sorted mosaics of shell, cobbles and pebbles embedded in or lying upon mud, sand or gravel. Due to the variable nature of the seabed a variety of communities can develop which are often very diverse. A wide range of infaunal polychaetes, bivalves, echinoderms and burrowing anemones such as *Cerianthus lloydii* are often present in such habitat and the presence of hard substrata (shells and stones) on the surface enables epifaunal species to become established, particularly hydroids such as *Nemertesia* spp and *Hydrallmania falcata*. The combination of epifauna and infauna can lead to species rich communities'.



Seabed images at Station 9 (left) and Station 18 (right) to show varying component of gravels in mixed sediments.



Level 5 (Biotope) & Level 6 (Sub-biotope)

A5.44(7) = SS.SMx.CMx.PoBivAmp
Infaunal polychaetes with burrowing bivalves and amphipods in circalittoral mixed sediment

This new EUNIS Level 5 biotope reflects a functional assemblage consisting of a mixture of epifaunal species on the gravels and infaunal species in the finer sediments in between. This biotope of infaunal polychaetes, burrowing bivalves and amphipods has been well described here and in fine sediments in the Humber REC (Biotope A5.25(41)).

There are a total of 12 stations within this biotope, split between 2 sub-biotopes on the basis of different species within the same functional group.

A5.44(71) = SS.SMx.CMx.ApriBelePo
Abra prismatica, *Bathyporeia elegans* and polychaetes in sandy mixed sediment

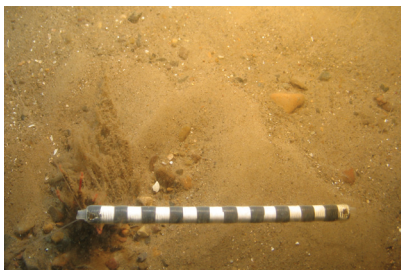
There are six stations (Stations 4, 9, 27, 51, 93 and 133) assigned to this sub-biotope. It has fairly high diversity, with 118 species of infaunal and epifaunal animals which reflects the mixed nature of the sediments.

It is numerically dominated by infaunal polychaetes including *Ophelia borealis*, *Polycirrus*, *Notomastus* and *Glycera* and nematode worms. Also present within the sediment are burrowing bivalves including *Goodallia* and *Nucula* and amphipods such as *Urothoe*, *Stenathoe* and *Bathyporeia*.

The presence of gravels and pebbles provides attachment for a range of epifaunal animals including barnacles, hydroids and bryozoans. *Flustra foliacea* is observed in several video stills as is 'dead man's fingers' *Alcyonium digitatum*.



Seabed image at Station 9 (left) where hydroids and bryozoans are attached to gravels and pebbles within the sandy sediments. The mobile starfish *Asterias rubens* is frequently observed. Attached hydroids and gravels and pebbles are visible at Station 93 (right).



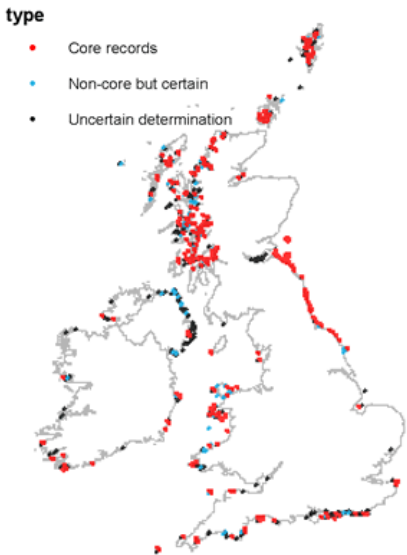
Level 6 (Sub-biotope)

A5.44(72) = SS.SMx.CMx.AalbUelePo
Abra alba, *Urothoe elegans* and polychaetes in circalittoral sandy mixed sediment

Six stations (6, 18, 19, 23, 101 and 126) are assigned to this species specific variant of the biotope A5.44(7). This sub-biotope is dominated and characterized by a diverse range of infaunal polychaetes, particularly *Polycirrus*, *Aonides* and *Mediomastus*. There are several species of burrowing amphipods including *Urothoe* spp. and the bivalve *Abra alba* is present although not in particularly high abundance.



Specimen photographs of typical fauna found in sub-biotope A5.44(72): *Abra alba* (top left), *Mediomastus* (top right), *Aonides* (bottom left) and *Urothoe* (bottom right) (© seasurvey.co.uk).



Distribution map for EUNIS biotope complex A5.44 (Marine Habitat Classification code SS.SMx.CMx) (Source: Conner *et al.* 2004, Internet data accessed 15/11/10).

A5.4 — Sublittoral mixed sediment (SS.SMx)

Level 5 (Biotope)

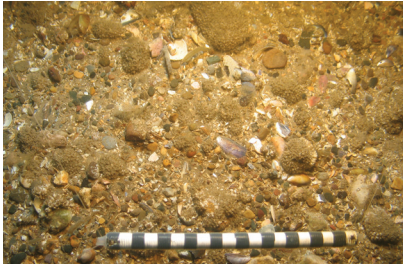
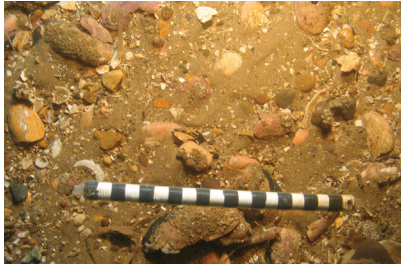
Level 5 (Biotope)

Levels 5 (Biotope)

A5.44(8) = SS.SMx.CMx.BaAscPo

Barnacles, ascidians and tube worms on circalittoral mixed sediment

This newly defined biotope was fairly common across the Humber REC area, being recorded at 22 stations. It is also recognized at many stations in other areas, being an assemblage type typical of circalittoral mixed sediments. It is numerically dominated by encrusting organisms such as barnacles, ascidians, tube worms, hydroids and bryozoans that colonized the hard substrata. Functionally, the biotope is characterized by high numbers of filter feeding organisms and the moderate tidal energy of the area will provide a supply of food particles. All stations have been assigned to three Level 6 sub-biotopes.



The seabed at Station 2 (A5.4491), Station 12 (A5.4492) (top left), Station 96 (A5.4493) (bottom left) and Station 137 (A5.4493) (bottom right).

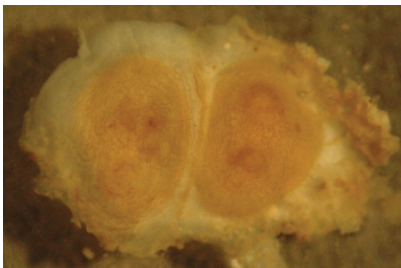
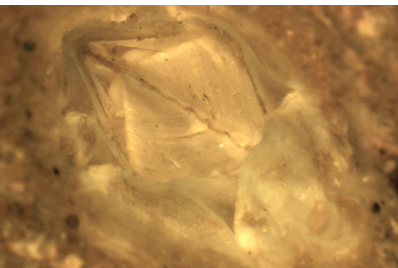
A5.44(81) = SS.SMx.CMx.BcreCdunDgro

Balanus crenatus, *Chone duner* and *Dendrodoa grossularia* on circalittoral mixed sediment

This sub-biotope was assigned to stations 2, 15, 68, 99, 129 and 136 where the surface sediments are characterized by gravels and shells in particular with some pebbles and cobbles and very occasional boulders.

There is frequent epifaunal visible on the video stills images, particularly barnacles, tube worms, hydroids such as *Tubularia*, the bryozoans *Flustra foliacea* and several mobile epifaunal species especially the echinoderms *Echinus esculentus* and *Asterias rubens*.

This variant is characterized by high abundances of the barnacle *Balanus crenatus*, the ascidian *Dendrodoa grossularia* and the sabellid tube worm *Chone duner*. Mixed sediments are characterized by sands between the larger gravels and cobbles and this supports an abundant assemblage of infaunal polychaetes including *Polycirrus*, *Spio* spp. Other encrusting and epifaunal animals such as *Sabellaria spinulosa* and *Mytilus edulis* may also be present in high abundance.



Specimen images of *Balanus crenatus* (top left), *Dendrodoa grossularia* (top right), *Chone duner* (bottom left) and *Spio* sp. (bottom right). (© seasurvey.co.uk).

A5.44(82) = SS.SMx.CMx.DgroPlamBa

Dendrodoa grossularia, *Pomatoceros lamarki* and barnacles on circalittoral mixed sediment

This sub-biotope is also numerically dominated by the barnacle *Balanus crenatus* but is characterized by higher abundance of *Dendrodoa* and the presence of *Pomatoceros*.



Specimen images of *Pomatoceros lamarki* and ascidians. (© seasurvey.co.uk).

A5.44(83) = SS.SMx.CMx.BcrePlamUele

Balanus crenatus, *Pomatoceros lamarki* and *Urothoe elegans* in circalittoral mixed sediment

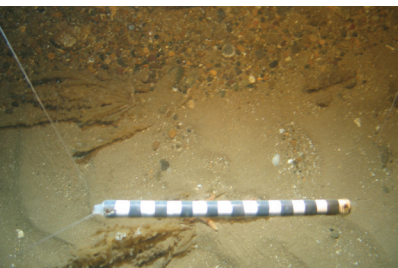
This variant of the biotope was assigned to Stations 60, 69, 89, 91, 96, 98, 109, 118 & 137) and is primarily distinguished by the presence of the encrusting tube worm *Pomatoceros lamarkii* and the burrowing amphipod *Urothoe elegans* in addition to encrusting barnacles and ascidians.

A5.44(A) = SS.SMx.CMx.SpF

Sparse fauna in circalittoral mixed sediment

This newly specified biotope was recorded at 6 stations (28, 32, 35, 70, 125 & 127), mainly in the western sector of the REC study area. It had an average abundance of 25 individuals and 15 species per grab although across the whole group of six samples diversity is much higher (71 species).

The most common animals in this biotope are infaunal polychaetes, including *Glycera* and *Spiophanes*, *nematodes* and some encrusting fauna such as were recorded in grab samples. From the video still images the epifaunal cover was generally sparse and patchy, with ephemeral hydroids, the bryozoans *Flustra foliacea* and *Alcyonidium diaphanum*, barnacles and a few anemones



Mixed substrate at Stations 70 (top) & 125 (bottom) and two infaunal taxa, *Glycera* sp. (top) and *Spiophanes* (bottom). (© seasurvey.co.uk).

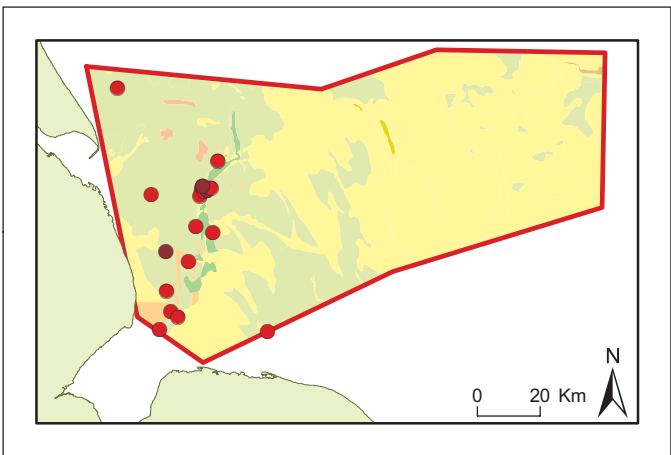
A5.6 — Sublittoral biogenic reefs (SS.SBR)

Level 4 (Biotope Complex)

The EUNIS Level 3 habitat type includes polychaete reefs, bivalve reefs (e.g. mussel beds) and cold water coral reefs. These communities develop in a range of habitats from exposed open coasts to estuaries, marine inlets and deeper offshore habitats and may be found in a variety of sediment types and salinity regimes.

There were a total of 20 stations assigned to biogenic reefs. These were located in areas of circalittoral muddy sand (A5.26), deep circalittoral sand (A5.27), circalittoral mixed sediments (A5.44) and deep circalittoral mixed sediments (A5.45).

A5.61 = SS.SBR.PoR
Sublittoral polychaete worm reefs on sediment



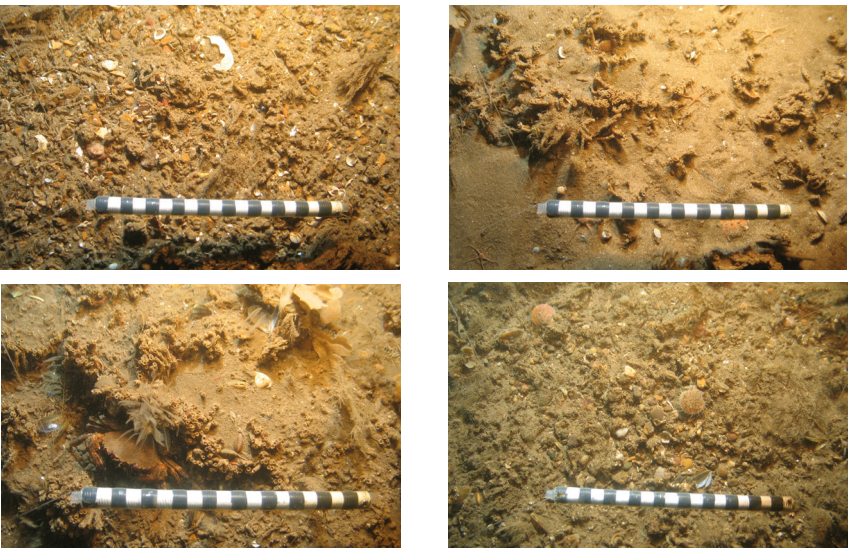
Location of stations within the EUNIS A5.61.

This is a biotope complex covering 17 of the Humber REC stations in the west of the study, predominantly in the sandy and muddy sediments of Silver Pit.

EUNIS describes this biotope complex as 'Sublittoral reefs of polychaete worms in mixed sediments found in a variety of hydrographic conditions. Such habitats may range from extensive structures of considerable size to loose agglomerations of tubes. Such communities often play an important role in the structural composition or stability of the seabed and provide a wide range of niches for other species to inhabit. Consequently polychaete worm reefs often support a diverse flora and fauna' and the presence of hard substrata (shells and stones) on the surface enables epifaunal species to become established, particularly hydroids such as *Nemertesia* spp and *Hydrallmania falcata*. The combination of epifauna and infauna can lead to species rich communities."

The biogenic reef at these stations is produced by the aggregated tubes of *Sabellaria spinulosa* and so a species specific Level 6 category has been defined.

Level 5 (Biotope) & Level 6 (Sub-biotope)

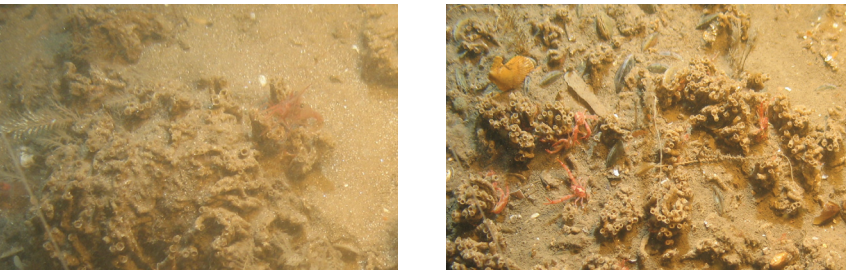


Seabed images at Station 37 (in circalittoral muddy sand), Station 75 in deep circalittoral sand, Station 34 in circalittoral mixed sediments and Station 31 in deep circalittoral mixed sediments.

A5.61(1) = SS.SBR.Sabspin
Sabellaria spinulosa on stable circalittoral mixed sediment

Aggregations of the sandy tubes of *Sabellaria spinulosa* are visible in the seabed images from the stations assigned to this biotope. The stations are 11, 31, 33, 34, 37, 50, 52–54, 57, 75, 77–80, 82 & 97. Most of the aggregations appear relatively patchy but do appear to consolidate the sediments.

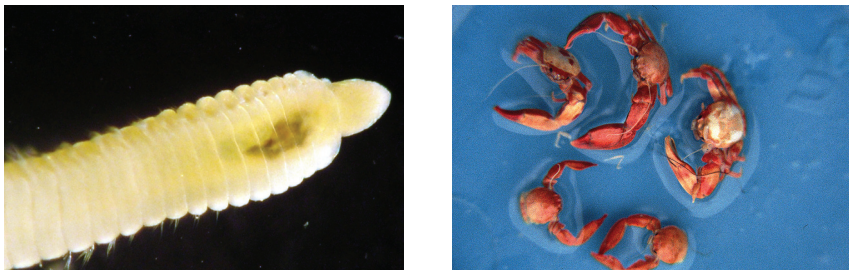
The video stills show there were several mobile epifaunal species associated with the reefs including the queen scallop *Aequipecten opercularis* (Figure 7.54), the squat lobster *Galathea* and the pink shrimp *Pandalus* which is known to feed on *Sabellaria*.



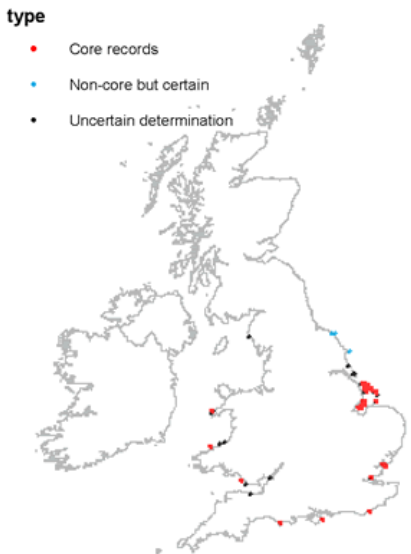
Specimen photographs of typical fauna found in sub-biotope A5.611 includes hydroids and the pink shrimp *Pandalus* (left) and the squat lobster *Galathea* (right).

The grab samples from these stations are dominated by high abundance of *Sabellaria spinulosa* with an associated assemblage of epifauna and infauna. Ascidians were present at most stations and the encrusting tube worm *Pomatoceros lamarckii* was observed in high abundance but was not present at all stations. Several polychaete species were characteristic of this biotope, particularly *Lumbrineris gracilis* but *Polydora*, *Polycirrus* and *Mediomastus* were also present. The pea crab *Pisidia longicornis* was also present at some stations and the infaunal bivalve *Abra alba* was often observed although not in high abundance.

Level 6 (Sub-biotope)



Specimen photographs of typical fauna found in sub-biotope A5.611 includes *Lumbrineris gracilis* and the pea crab *Pisidia longicornis*. (© seasurvey.co.uk).



Distribution map for EUNIS biotope complex A5.61 (Marine Habitat Classification code SS.SBR.PoR) (Source: Conner *et al.* 2004, Internet data accessed 17/11/10).

A5.6(4) = SS.SBR.MxR
Mixed biogenic reefs of sediment

This is a newly specified biotope to reflect the presence of mixed biogenic reef, which may include a reef matrix made up of polychaetes and bivalves or other combinations of faunal groups. Mixed biogenic reef was found at Stations 81, 83 and 132. A sub-biotope has been specified for these stations to reflect the actual combination of species present.

A5.6(41) = SS.SBR.SspiMedu
Sabellaria spinulosa and *Mytilus edulis* on circalittoral mixed sediment

This sub-biotope is very similar in species composition to A5.611 with the exception of high abundances of Mytilidae within the reef complex.

7.2 Habitat Suitability Modelling: RECHUMB

Habitat suitability modelling is a concept which has developed from the niche theory which states that every species depends upon the existence of a specific set of environmental conditions for its long-term survival (Hutchinson, 1957). There are two main approaches to habitat suitability modelling. The first is a mechanistic approach based on an understanding of the physiological limits of the species of interest (Guisan & Zimmermann, 2000). This approach is usually limited by our incomplete understanding of the physiology of the species which we hope to model. The second and more commonly applied approach to habitat suitability modelling is a correlative one, whereby the distribution of a species (or community) is related to the distribution of a number of environmental parameters (Soberón & Peterson, 2005). Essentially, the range of environmental conditions under which the species or community is observed, are projected in geographical space to reflect the distribution of suitable habitat. This approach was used by Robinson *et al* (2009) in the BIOMOR 5 project to predict the distribution of biotopes across the southern Irish Sea, and has been adopted here to map the probabilistic distribution of the biological communities across the Humber REC study area.

The distribution of species and communities is not only determined by the physical environment but also by biological aspects of the ecosystem including trophic interactions. Competition, predation, physical barriers to dispersal and colonisation and anthropogenic pressures will ultimately prevent a species from fully occupying the environmental niche which meets their requirements (Anderson *et al.* 2003). Instead a species almost always occupies a subset of their environmental niche, referred to as the realised niche (Hutchinson, 1957). The implication of this is that occurrence records by definition can only be sampled from the realised niche and predictions based on these records are therefore likely to underestimate potential distributions. In order to limit the effect of biological interactions on the model the functional biological communities have been chosen as the modelling unit. Grouping the biological communities at a functional level removes much of the species level variation which may be influenced by biological interactions. This was shown to improve the correlation between the biotic and abiotic components sampled from the Humber REC study area from $ps = 0.527$ to $ps = 1$ (Tables 6.5.2 and 6.5.3).

Following a similar methodology to that used in BIOMOR 5 (Robinson *et al.* 2009), this model uses a simple rule based approach to habitat suitability modelling. This allows for a wide range of different parameters as predictors and is not highly dependent on data quantity (as opposed to statistical methods, which are). The model 'RECHUMB: REC Humber Modelled Biotypes' has been formulated within an ArcGIS environment (v 9.3) using additional extensions and tools (Spatial Analyst, ET Geo Wizards 9.1, Benthic Terrain Modeler, Hawth's Tools 3.27), in-house developed VBA coding and also Excel spreadsheet macros and formulae. A summarised account of the input data, methods and output are provided below whilst more detailed data processing of GIS layers is provided in Appendix E.

7.2.1 Preparation of Model Input Data

Preparation of Full Coverage GIS Data

The RECHUMB model uses environmental data layers that were previously processed for the EUNIS model, as described in Chapter 7.1 and Appendix E. These data were supplemented by a range of additional environmental datasets including statistics derived from the seabed bathymetry and modelled oceanographic data. The environmental data layers which were ultimately included in the model were chosen on the basis of the strength of correlation between them and the functional biological communities (Table 6.5.3) as well as some degree of expert judgement. Correlations were determined through multivariate statistical analyses using the PRIMER (v6) package (Chapter 6.5) and correlation tests in Excel. All environmental data considered during the development of the model are summarised in Table 7.2.1 along with the criteria for excluding some environmental data from the model. The technical details of how individual datasets were processed prior to use in the model can be found in Appendix E.

Relationships Between Functional Biological Communities and Environmental Parameters

Once all of the environmental datasets listed in Table 7.2.1 were processed and mapped in GIS, they were then overlaid with the biological sampling stations. The value of each environmental parameter at each of the sampling stations could then be extracted using the 'Spatial Join' ArcGIS tool. It was then possible

to summarise the range of environmental conditions over which each of the functional biological communities were found. The environmental niche of each functional community could then be described in terms of the minimum, maximum, average and standard deviation for numerical datasets; and lists of types and number of occurrences for categorical datasets. For example, 'Barnacles, ascidians and tube worms' were found in areas with percentage gravel (numerical dataset) between 18.8 and 81.4%, average of 45.4% and standard deviation of 19.1 and on bedform types (categorical dataset) 'area of sandwaves' (2 occurrences), 'tunnel valley' (3 occurrences), 'submarine channel' (one occurrence) and 'no bedform feature' (25 occurrences).

The environmental niche descriptors which were output from this process were further refined to remove any outliers. All exclusions were carried out under the supervision of expert judgment so that only environmental conditions that were truly beyond or at the extreme limit of a community's niche were removed as follows;

Numerical datasets: outliers that exceeded 2 x the standard deviation identified for each functional biological community were removed from the range of environmental conditions derived as niche descriptors. Using this rule for the environmental parameter 'depth' (bathymetry), some functional biological communities would have the very deep tunnel valleys excluded from their environmental niche. However, since these features were observed to be an important habitat for several of the functional biological communities, extreme depths were not excluded from niche descriptors.

Categorical datasets: those categories that only occurred in a minority of stations were excluded from the niche descriptions. Exceptions were again made on the basis of expert judgment, for example seabed types were only removed from a community's niche where there was evidence to suggest that this community might not be able to exist there.

Once the environmental parameters were finalised for each functional biological community it was necessary to develop categories for the numerical environmental datasets so that they can be modelled. For each numerical dataset, categories were set up between 1 and 6. The values assigned to each class are shown in Table 7.2.2. The values used for the classes reflect the full range

Data Type	Parameter	Used in Final Model	Source	Alternatives considered and assessed in multivariate analyses and model tests
Geology	% Gravel	✓	REC	Folk sediment class and EUNIS substrate type (Figure 7.1.4) which were not highly correlated with the distribution of the functional biological communities and % Sand which was excluded on the basis that it shows a strong inverse correlation with % Gravel
	% Mud	✓	REC	
	Bedform type	✓	REC	
	Bedrock	✓	REC	
	Boulders bank	Excluded as covers all except a very small area of the Humber REC which showed no relationship to functional biological communities	REC	
	Botney Cut	✓	REC	
Bed stress	Maximum wave and tidal bed shear stress	✓	UKSeaMap 2010	Department of Business Enterprise and Regulatory Reform (BERR) wave and tidal atlases and Proudman Oceanographic Laboratories (POL) maximum mean spring tidal current depth averaged (m/s), as used in the EUNIS model (Figure 7.1.5) . In both cases data is depth averaged so not ideal to pick out detail at seabed.
Water Column	Near bed salinity	✓	MyOcean (POL)	ICES Annual mean, amplitude and month of maximum but depth averaged so not ideal to pick out detail at seabed
	Near bed temperature	✓	MyOcean (POL)	ICES Annual mean, amplitude and month of maximum but depth averaged so not ideal to pick out detail at seabed
	Water Stratification (Winter)	✓	UKSeaMap 2006	Water stratificaion in other seasons and distance to land, neither of which were found to be strongly correlated with the distribution of functional biological communities
Bathymetry	Bathymetry	Excluded as statistical methods identified the tunnel valleys as outliers yet these represent important habitats for a number of the functional biological communities (see below)	SeaZone	Rugosity (calculated) was excluded becasue it was found to to be strongly correlated with slope due to the model resolution
	Slope	✓	Calculated from bathymetry	
Biological zones	Photic maximum	✓	UKSeaMap2006	
	Wavebase	✓	UKSeaMap2006	

Table 7.2.1: Environmental datasets considered for inclusion in the RECHUMB model, data source and reason for exclusions where not used in the final model.

of the dataset once the outliers had been removed. The final range of environmental parameter classes used in the model for each functional biological community is presented in Table 7.2.3.

7.2.2 Modelling the Distribution of Functional Biological Communities

The categorised environmental layers were combined in shapefile polygon GIS format using the ‘union’ process which creates individual polygons (areas) with unique combinations of environmental scores and categories (Table 7.2.3). From this point it was possible to develop a set of classification rules upon which

each polygon could be assessed for the likelihood of it containing each of the functional biological communities.

Probabilistic Distribution of the Four Functional Biological Communities

The likely distribution of each of the functional biological communities was derived through a series of model runs (A-G), carried out using different combinations of environmental variables, as summarised in Table 7.2.4. Each of the modelled polygons were queried, using VBA code within the ArcGIS environment, to determine how well the environmental conditions in that modelled

Parameter	Class Assigned					
	1	2	3	4	5	6
Gravel %	0–15	15–30	30–45	45–60	60–90	90–100
Mud %	0–3	3–6	6–9	9–12	12–15	15–18
Salinity (psu)	32.5–33	33–33.5	33.5–34	34–34.5	34.5–35	35+
Temperature (°C)	3–4	4–5	5–6	6–7	7–8	8–9
Slope (degrees)	0–2.5	2.5–5	5–7.5	7.5–10	10–12.5	12.5+
Wave and tidal bed shear stress (Newtons/ m²)	0–15	15–30	30–45	45–60	60–75	75–90

Table 7.2.2: Classes assigned to numerical environmental datasets.

polygon match the environmental niche requirements derived for each functional biological community (Table 7.2.3). A maximum score, equal to the number of environmental variables included in that run of the model, was achieved when all of the environmental parameters of the modelled polygon fell within the range derived for the biological community. A score of zero was given when all of the environmental parameters within that polygon fell outside the range derived for that functional biological community.

Weightings were introduced, in model runs F and G, so that they better reflected the importance of each parameter. For example, Model F had weights applied to percentage gravel, percentage mud and slope because analysis in PRIMER found these to be important determinants of the distribution of the Functional Biological Communities (Table 7.2.4). Gravel and sand are highly correlated and so percentage gravel is a proxy for percentage sand and vise-versa. In model G gravel and mud have been replaced by the Folk sediment class to determine if this was a better fit.

Dealing with Overlapping Distributions

The likelihood of each of the four functional biological communities occurring was calculated for every polygon of the model, in each of the model runs. The functional biological community with the highest score in any one polygon was then assumed as the most likely to occur in that location. However, there were many instances where the likelihood of two or more functional biological

Functional Biological Group	Environmental Variable	Environmental Niche Scores/Categories
1 — <i>Barnacles, ascidians and tubicolous polychaetes</i>	% Gravel	2 to 6
	% Mud	1
	Near bottom salinity	3 to 5
	Near bottom temperature	3 to 5
	Slope	1
	Wave and tidal bed shear stress	1 to 6
	Bedform	Sediment Sheet, Tunnel Valley, Area of Sandwaves, Submarine Channel
	Rock Outcropping	Present, Absent
	Botney Cut	Present, Absent
	Wavebase	Above wavebase
	Water Stratification (Winter)	Well-mixed ROFI(Region of freshwater influence), Well-mixed shelf water
2 — <i>Infaunal polychaetes with burrowing bivalves and amphipods</i>	Gravel percentage	1 to 3
	Mud percentage	1 to 2
	Near bottom salinity	3 to 5
	Near bottom temperature	3 to 4
	Slope	1
	Wave and tidal bed shear stress	1 to 3
	Bedform	Sediment Sheet, Tunnel Valley, Area of Sandwaves, Sand Bank
	Rock Outcropping	Present, Absent
	Botney Cut	Present, Absent
	Wavebase	Above wavebase, Below wavebase
	Water Stratification (Winter)	Well-mixed shelf water, Well-mixed ROFI
3 — <i>Sabellaria spinulosa</i> reef	Gravel percentage	1 to 4
	Mud percentage	1 to 6
	Near bottom salinity	1 to 4
	Near bottom temperature	1 to 4
	Slope	1 to 4
	Wave and tidal bed shear stress	1 to 5
	Bedform	Sediment Sheet, Tunnel Valley, Glaciofluvial Outwash Fan
	Rock Outcropping	Present, Absent
	Botney Cut	Absent
	Wavebase	Above wavebase, Below wavebase
	Water Stratification (Winter)	Well-mixed ROFI
4 — <i>Sparse fauna</i>	Gravel percentage	1 to 5
	Mud percentage	1
	Near bottom salinity	2 to 5
	Near bottom temperature	3 to 4
	Slope	1
	Wave and tidal bed shear stress	1 to 5
	Bedform	Sediment Sheet, Sand Bank, Area of Sand Waves
	Rock Outcropping	Absent
	Botney Cut	Absent
	Wavebase	Above wavebase
	Water Stratification (Winter)	Well-mixed ROFI, Well-mixed shelf water

Table 7.2.3: Environmental niche descriptors (scores & categories) identified for each of the functional biological communities identified in the Humber REC study area.

communities occurring in any one polygon was equal. In these cases a combination of functional biological communities was returned by the model. This could be considered as representative of the overlap in the environmental requirements of these communities. However, for the purposes of creating a map useful for marine planning it is important to reduce the areas of the overlap as much as possible.

For each model run, the area predicted to contain more than one functional biological community was calculated and compared (Figure 7.2.1). The model runs yielding the smallest area of overlapping distributions were assumed to be making the best predictions since they were most successful in separating the niche requirements of functional biological communities.

Model runs A, B and F predicted the smallest area of overlapping distributions. However, model runs A and B included two different and potentially conflicting sediment descriptors (% gravel/sand/mud and Folk sediment class) and hence were not deemed suitable for use in the final model. Model run F was therefore chosen as the preferred combination of environmental variables and weighting to be used in the RECHUMB model. The predicted distribution of each functional biological community using this model is illustrated in Figure 7.2.2. These figures illustrate a good correspondence between the predicted distributions and the observations made which is another indicator that this model is making accurate predictions.

Despite the high level of correspondence between the probabilistic distributions of the functional biological communities and the observed distributions a high level of overlap remains a feature of this model (Figure 7.2.3). The area of overlap in the model was further reduced by forcing polygons to be classified by any observations they contain.

Since the functional biological communities correlated very strongly with the sediment composition (Table 6.5.3), this variable was used to determine the community most likely to occur in overlapping polygons where no observational data was available. For example, if a polygon was predicted to contain communities 1 and 2 but the sediment composition (% gravel/% mud) fell outside of the range derived for community 1 but within the range derived for community 2 then the polygon would be assigned to community 2.

Parameter	A	B	C	D	F	(F weighting)	G	(G weighting)
Gravel Percentage	✓	✓	✓		✓	2		
Sand Percentage	✓							
Mud Percentage	✓	✓	✓		✓	2		
Near bed salinity	✓	✓	✓	✓	✓	1	✓	1
Near bed temperature	✓	✓	✓	✓	✓	1	✓	1
Slope	✓	✓	✓	✓	✓	2	✓	2
Wind and tidal bed shear stress	✓	✓	✓	✓	✓	1	✓	1
Bedform type	✓	✓	✓	✓	✓	1	✓	1
Folk sediment class	✓	✓		✓			✓	4
Outcrop	✓	✓	✓	✓	✓	1	✓	1
Botney Cut	✓	✓	✓	✓	✓	1	✓	1
Wave base	✓	✓	✓	✓	✓	1	✓	1
Winter water body	✓	✓	✓	✓	✓	1	✓	1

Table 7.2.4: Model runs carried out showing parameters used to score the likelihood of the polygons containing the four functional biological communities. The highlighted columns showing model F is the final version used for RECHUMB.

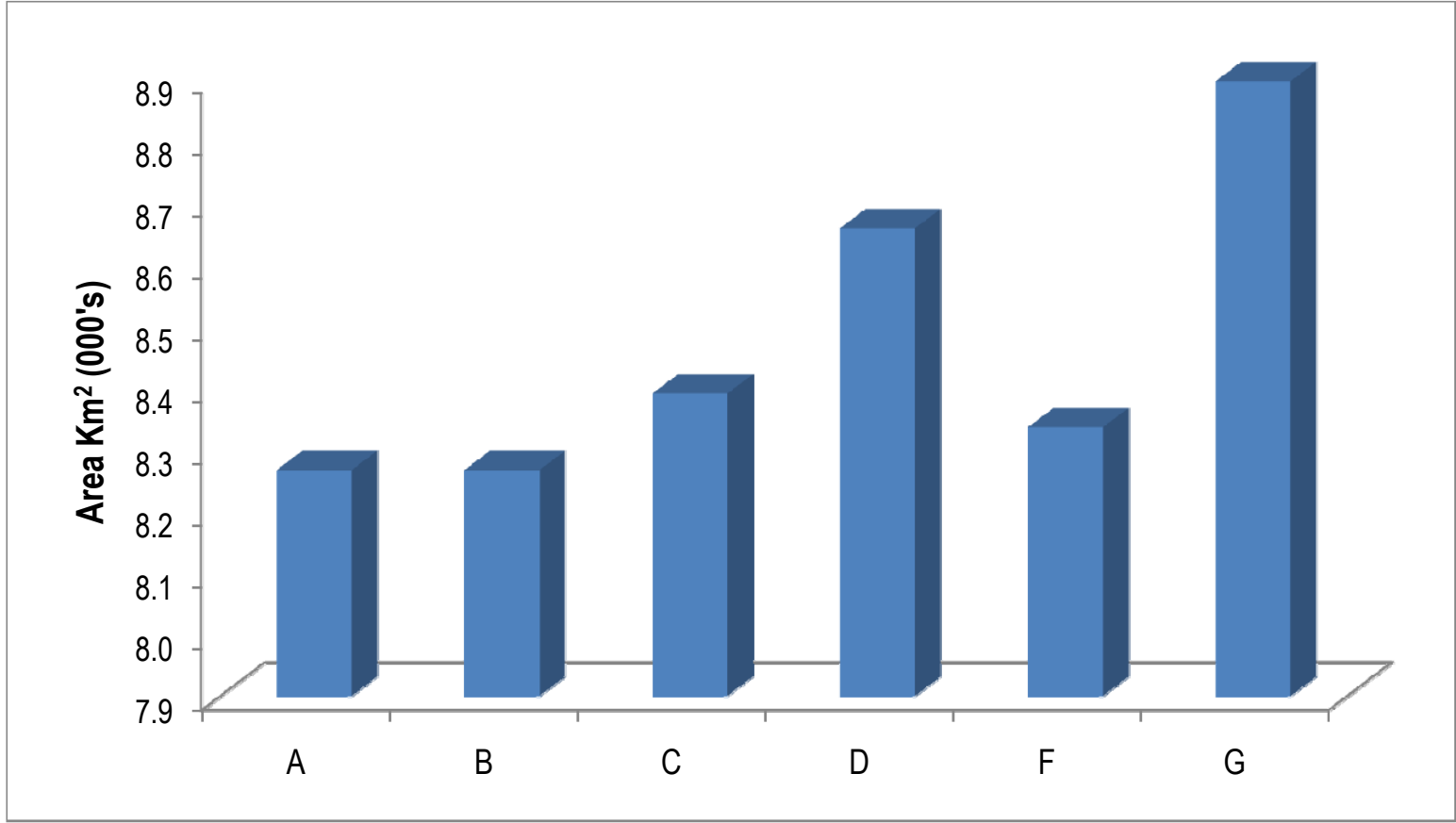


Figure 7.2.1: Area km² (000's) predicted to contain more than one functional biological community in each of the model runs.

The model areas forced by observations and/or sediment composition are illustrated in Figure 7.2.3. In the final model 25% of the area is either confirmed or forced by the observed distributions of the four functional biological communities and hence we can be reasonably confident of the model predictions in these areas. The remaining 75% of the modelled area was either forced or the predictions were confirmed by the (modelled) sediment composition, and given that the relationship between the biological communities and sediment composition is so strong we might also assume a relatively high degree of confidence in these areas.

The final RECHUMB model output showing the predicted distribution of the four functional biological groups across the Humber REC area is presented in Figure 7.2.4. The model has predicted that the majority of Humber REC contains suitable habitat to support functional biological community 2 'Infaunal polychaetes with burrowing bivalves and amphipods' which reflects the predominance of sandy deposits across the area and is strongly supported by observations made at the biological sampling stations. Moving further inshore the model becomes more complex and all four functional biological communities are predicted to occur reflecting the increased habitat heterogeneity. Functional biological communities 1 'Barnacles, ascidians, and tubiculous polychaetes' and 3 '*Sabellaria spinulosa* reefs' dominate the inshore area which is unsurprising given that both of these communities are dominated by epifaunal species which require some coarse sediment for attachment.

A relatively large area has been predicted to contain *Sabellaria spinulosa* reef which is a habitat of potential conservation interest. The predicted area correlated well with the observations made of this habitat but it should be noted that the model shows the predicted distribution of suitable habitat able to support this community. The patchy and ephemeral nature of these biogenic structures makes it highly unlikely that there is an extensive reef covering this entire area. This area could however be considered as a good area to search for *Sabellaria spinulosa* reef. Conversely the chance of finding such communities in the eastern half of the Humber REC study area could be considered to be quite slim. This type of information is likely to be of significant interest to the conservation agencies who are tasked with designing a coherent network of marine protected areas to conserve a large variety of

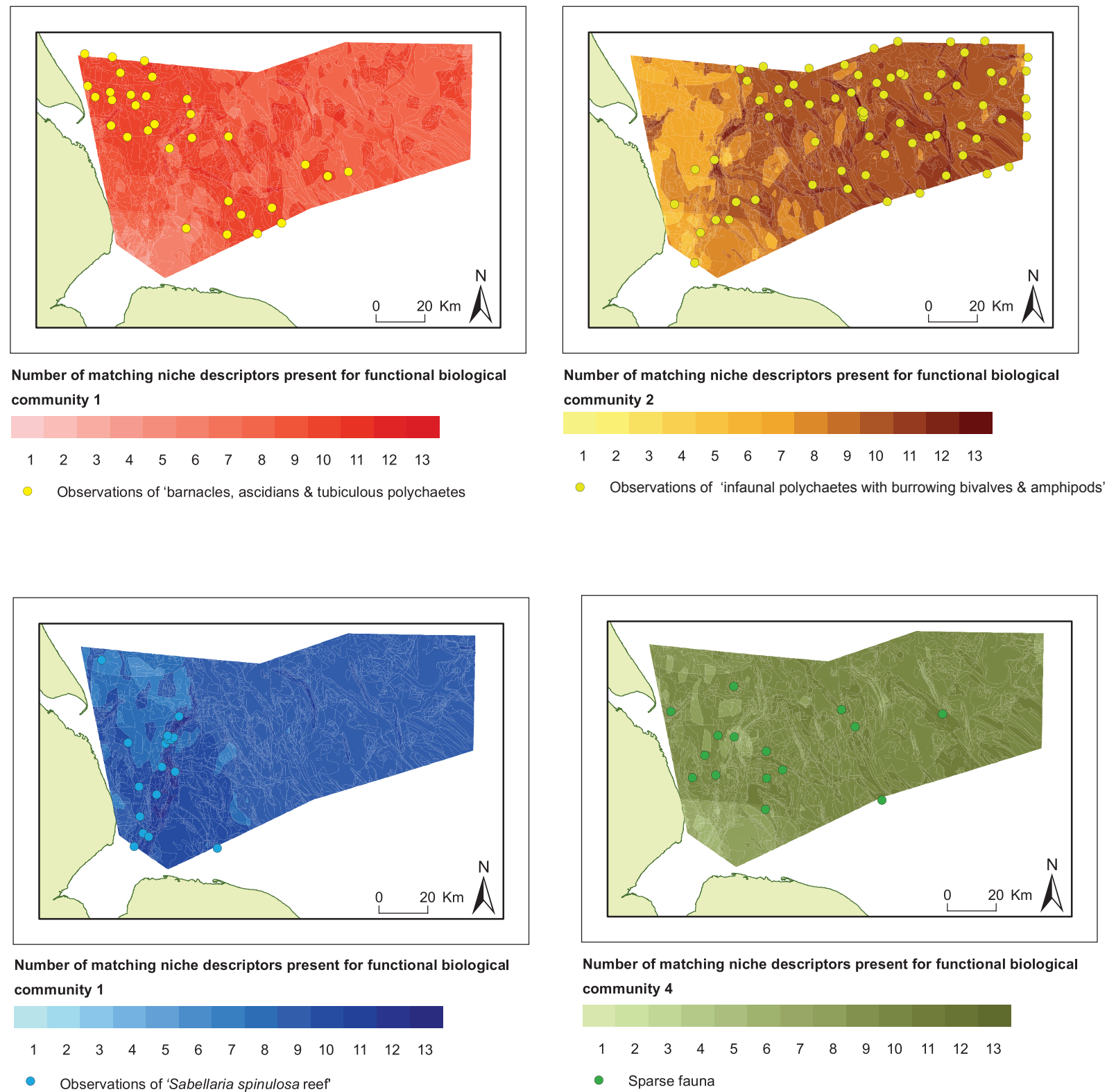


Figure 7.2.2: Modelled probabilistic distribution of the four functional biological communities across the Humber REC study area. Also shown are the recorded observations from the biological sampling stations.

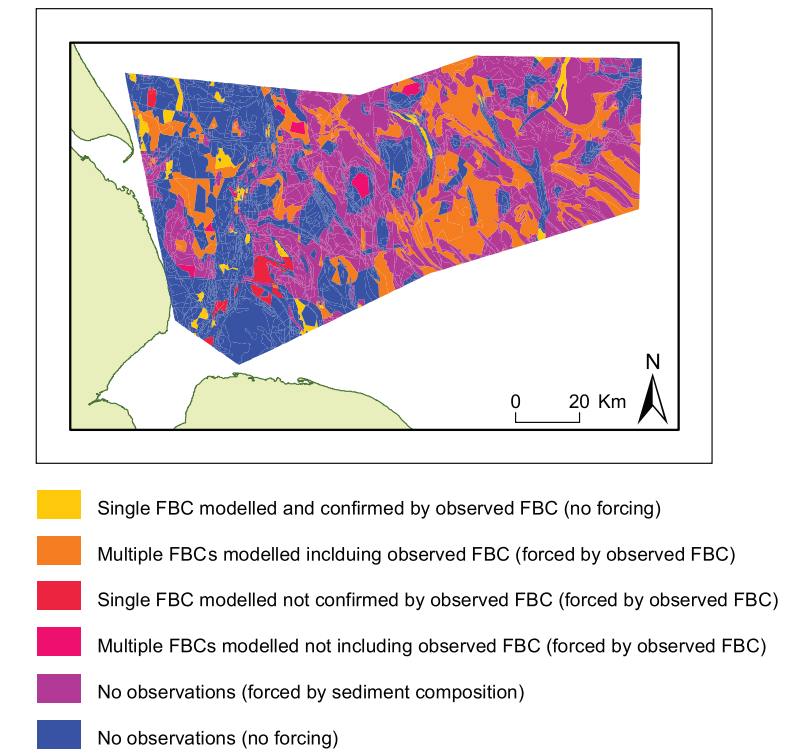


Figure 7.2.3: Chart showing the model areas where forcing has been applied on the basis of observed functional biological communities (FBC) and sediment composition.

habitats including biogenic reefs. This is discussed in more detail in Chapter 8.2.

7.2.3 Creating a full coverage biotope model (EUNIS Level 5)

The RECHUMB habitat suitability model, which illustrates the predicted distribution of biological communities across the Humber study area, was combined with the EUNIS habitat model (level 4) as a means of generating a full coverage biotope model of the area.

The full coverage biotope model was created in ArcGIS with a 'union' of the habitat model (Figure 7.1.6) and the RECHUMB biological community model (Figure 7.2.4). This process divides areas where necessary to create unique combinations of Level 4 EUNIS biotopes and the biological community most likely to occur there. These combinations are equivalent to Level 5 in the EUNIS classification scheme and as such were assigned to biotope

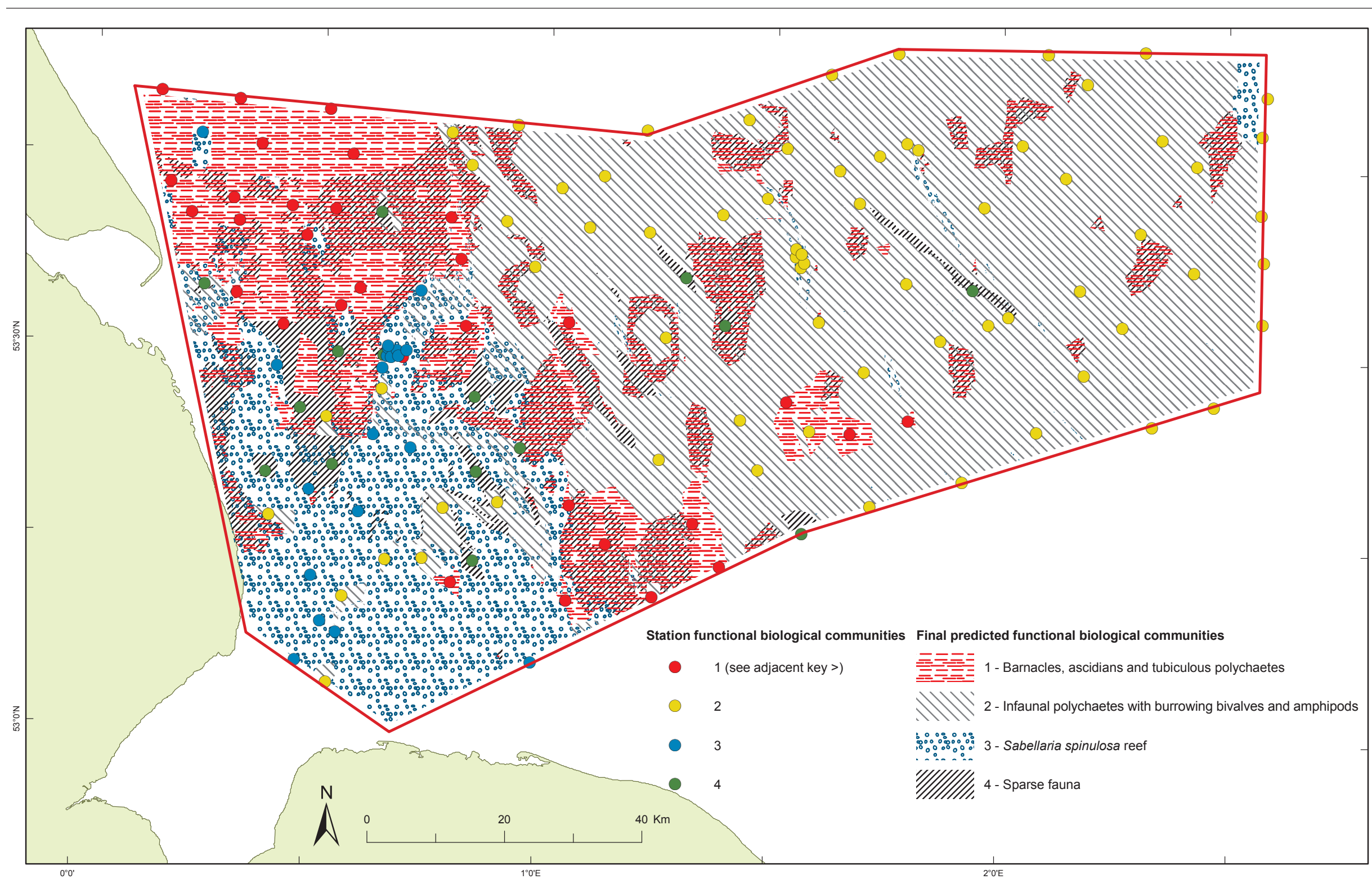


Figure 7.2.4: Final RECHUMB model showing the predicted distributions of the four functional biological communities; 1. Barnacles, ascidians and tubicolous polychaetes 2. Infaunal polychaetes with burrowing bivalves and amphipods 3. *Sabellaria spinulosa* reef 4. Sparse fauna. Where more than one FBC has been predicted to occur multiple numbers are given in the legend. The map also shows the observed distribution of these communities across the Humber REC sampling stations.

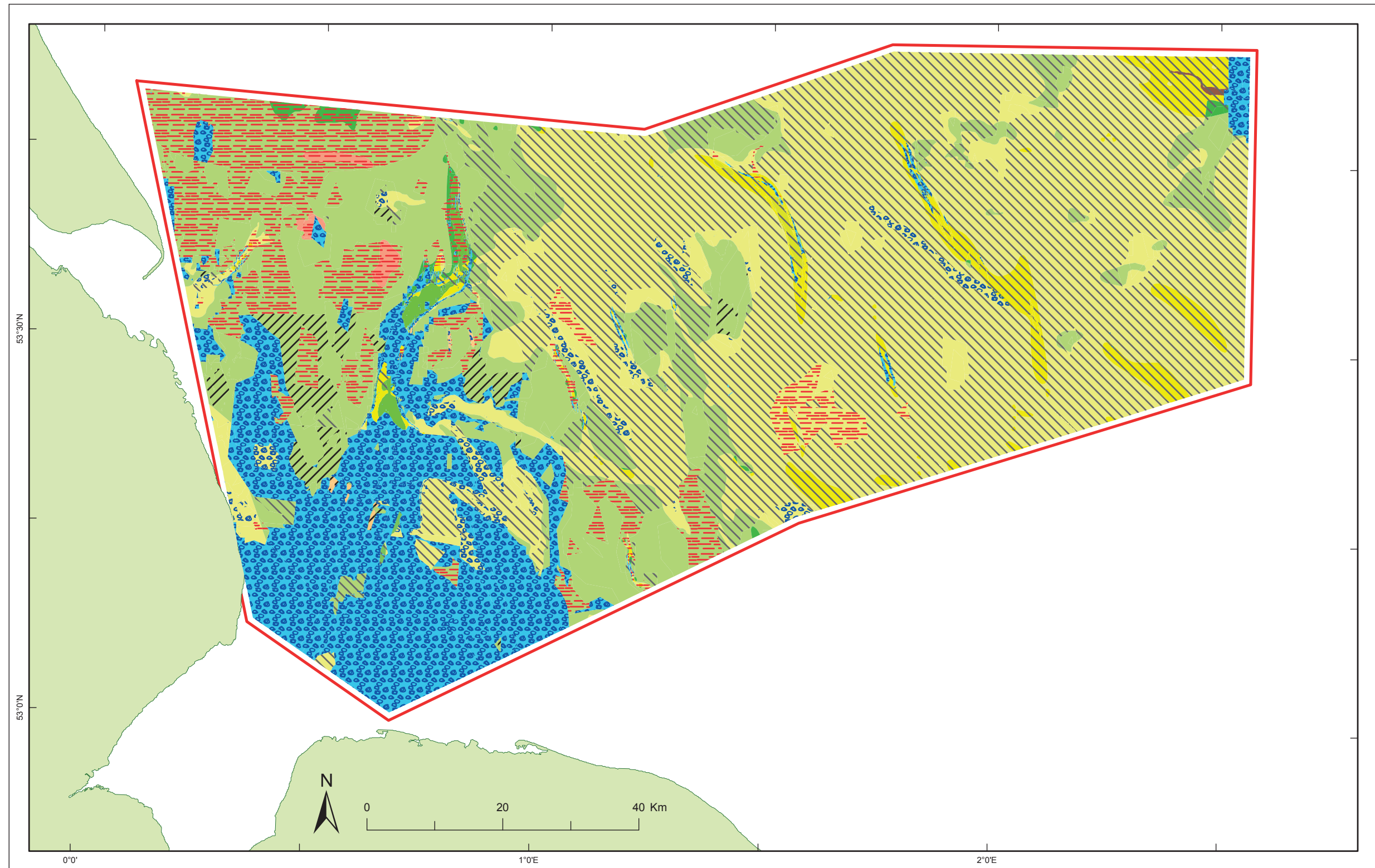


Figure 7.2.5: Map of the full coverage biotope model. This model combines modeled habitat (EUNIS Level 4—see Fig. 7.1.6) and modeled biology (RECHUMB model of functional biological groups—see Fig. 7.2.4) to give a map of predicted biotopes at EUNIS Level 5.

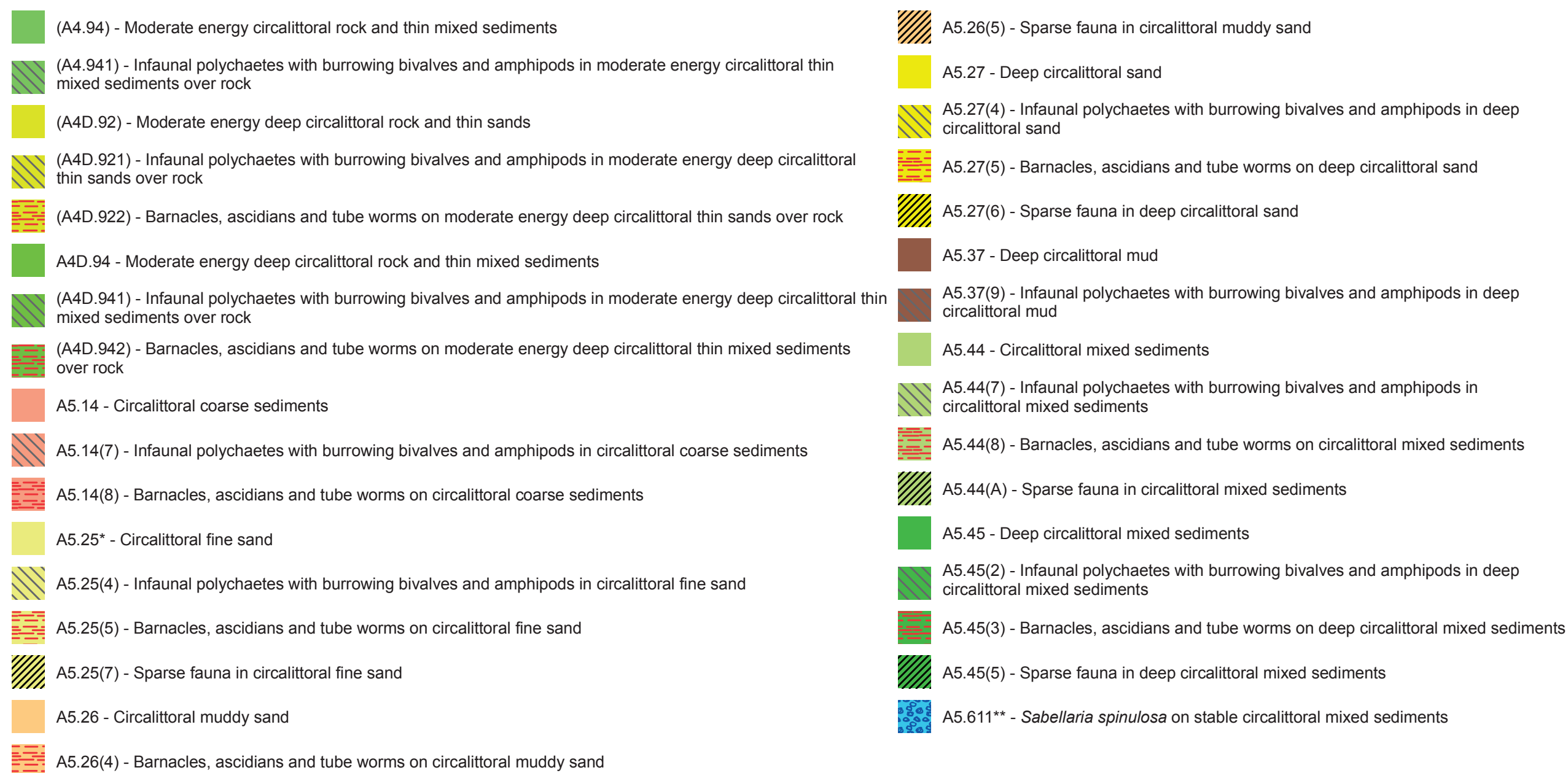


Figure 7.2.5: Legend.

descriptions through careful consultation of the 2006 EUNIS classification scheme and comparisons with biotopes assigned using similar methods in the South Coast and Eastern English Channel Synthesis project (MEPF 09/P92).

The RECHUMB habitat suitability model of predicted biotopes was added to the EUNIS Level 4 model (see Figure 7.1.6) to generate a model which combines modeled habitat and modeled biology to give a map of predicted biotopes at EUNIS Level 5 (Figure 7.2.5). Level 5 biotopes first described in the South Coast and Eastern English Channel Synthesis report are indicated by*. Level 5 biotopes which are suggested as an outcome of this work are bracketed. Brackets in the latter case have only been assigned to the part of the code that is new, eg, A5.27(7), where the Level 4 biotope, A5.27, already exists but there was no matching biotope at level five (7) in the 2006 EUNIS scheme. Where the RECHUMB model predicted an equal likelihood of more than one biological community occurring within a particular polygon, the polygon has been mapped at EUNIS level 4 only (Figure 7.2.5) although the complete map including overlaps can be found in the project GIS. A full list of the EUNIS level 5 biotopes are also given in Table 7.2.5.

This assessment has resulted in a EUNIS Level 5 map which includes:

- One existing EUNIS category, A5.611 (*Sabellaria spinulosa* on stable circalittoral mixed sediment);
- 15 categories that were assigned as part of the South Coast and Eastern English Channel Synthesis project; and
- 10 new categories suggested as a result of this study.

Therefore, there are a total of 26 predicted Level 5 habitats.

It is worth noting that the existing EUNIS level 5 biotope, '*Sabellaria spinulosa* on stable circalittoral mixed sediments', is predicted to occur and was recorded in a much wider range of habitats than is suggested by the current name. Rather than proposing a further nine *Sabellaria spinulosa* biotopes that describe this variation it is suggested that A5.611 is given a less specific name such as '*Sabellaria spinulosa* reefs'.

EUNIS Level	EUNIS Code	EUNIS Name	In the SC & EEC Synthesis	In Model	In Points
1	A	Marine Habitats	Y	Y	Y
2	A4	Circalittoral rock and other hard substrata	Y	Y	Y
3	(A4.9)	Moderate energy, circalittoral rock and thin sediment	Y*	Y	Y
4	(A4.94)	Moderate energy, circalittoral rock and thin mixed sediments	Y*	Y	Y
5	(A4.941)	Infaunal polychaetes with burrowing bivalves and amphipods in moderate energy circalittoral thin mixed sediments over rock	Y*	Y	Y
6	(A4.9411)	<i>Abra prismatica</i> , <i>Bathyporeia elegans</i> and polychaetes in moderate energy circalittoral thin mixed sediments over rock		Y	Y
5	(A4.945)	Sparse fauna in moderate energy circalittoral thin mixed sediments over rock		Y	
3	A4D.9	Moderate energy, deep circalittoral rock and thin sediment	Y	Y	Y
4	(A4D.92)	Moderate energy, deep circalittoral rock and thin sands	Y*	Y	
5	(A4D.921)	Infaunal polychaetes with burrowing bivalves and amphipods in moderate energy deep circalittoral thin sands over rock	Y*	Y	
6	(A4D.9211)	Dense <i>Abra alba</i> with <i>Amphiura filiformis</i> and <i>Mysella bidentata</i> in moderate energy deep circalittoral thin sands over rock			Y
5	(A4D.922)	Barnacles, ascidians and tube worms on moderate energy deep circalittoral thin sands over rock		Y	
6	(A4D.9221)	<i>Balanus crenatus</i> , <i>Chone duneri</i> and <i>Dendrodoa grossularia</i> on moderate energy deep circalittoral thin sands over rock			Y
4	A4D.94	Moderate energy, deep circalittoral rock and thin mixed sediments	Y*		
5	(A4D.941)	Infaunal polychaetes with burrowing bivalves and amphipods in moderate energy deep circalittoral thin mixed sediments over rock	Y*	Y	
5	(A4D.942)	Barnacles, ascidians and tube worms on moderate energy deep circalittoral thin mixed sediments over rock	Y*	Y	Y
6	(A4D.9421)	<i>Balanus crenatus</i> , <i>Chone duneri</i> and <i>Dendrodoa grossularia</i> on moderate energy deep circalittoral thin mixed sediments over rock			Y
2	A5	Sublittoral Sediment	Y	Y	Y
3	A5.1	Sublittoral coarse sediments	Y	Y	Y
4	A5.14	Circalittoral coarse sediments	Y	Y	Y
5	A5.14(7)	Infaunal polychaetes with burrowing bivalves and amphipods in circalittoral coarse sediments	Y*	Y	
5	A5.14(8)	Barnacles, ascidians and tube worms on circalittoral coarse sediments	Y*	Y	Y
5	A5.14(9)	Sparse fauna in circalittoral coarse sediments		Y	Y
3	A5.2	Sublittoral sand	Y	Y	Y
4	A5.25*	Circalittoral fine sand	Y	Y	Y
5	A5.25(4)	Infaunal polychaetes with burrowing bivalves and amphipods in circalittoral fine sand	Y*	Y	
6	A5.25(41)	<i>Abra prismatica</i> , <i>Bathyporeia elegans</i> and polychaetes in circalittoral fine sand			Y
6	A5.25(42)	<i>Abra alba</i> , <i>Urothoe elegans</i> and polychaetes in circalittoral fine sand			Y
5	A5.25(5)	Barnacles, ascidians and tube worms on circalittoral fine sand	Y*	Y	Y
6	A5.2551	<i>Balanus crenatus</i> , <i>Pomatoceros lamarki</i> and <i>Urothoe elgans</i> in circalittoral fine sand			Y
6	A5.2552	<i>Dendrodoa grossularia</i> , <i>Pomatoceros lamarki</i> and barnacles on circalittoral fine sand			Y
5	A5.25(7)	Sparse fauna in circalittoral fine sand		Y	Y
4	A5.26	Circalittoral muddy sand	Y	Y	Y
5	A5.26(3)	Infaunal polychaetes with burrowing bivalves and amphipods in circalittoral muddy sand	Y*	Y	

Table 7.2.5: Extract of the EUNIS classification table covering the biotopes identified as part of the Humber REC Project both in the Level 5 model and through interpretation of the station level data (points). EUNIS codes in brackets are newly proposed biotopes which have not yet been incorporated in the official EUNIS biotope scheme. Y* indicates EUNIS biotopes that were previously proposed in the South Coast and eastern English Channel Synthesis project (MEPF 09/P92).

EUNIS Level	EUNIS Code	EUNIS Name	In the SC & EEC Synthesis	In Model	In Points
5	A5.26(4)	Barnacles, ascidians and tube worms on circalittoral muddy sand	Y*	Y	
5	A5.26(5)	Sparse fauna in circalittoral muddy sand		Y	
4	A5.27	Deep circalittoral sand	Y	Y	Y
5	A5.27(4)	Infaunal polychaetes with burrowing bivalves and amphipods in deep circalittoral sand	Y*	Y	Y
6	A5.27(41)	<i>Abra prismatica</i> , <i>Bathyporeia elegans</i> and polychaetes in deep circalittoral sand			Y
6	A5.27(42)	<i>Abra alba</i> , <i>Urothoe elegans</i> and polychaetes in deep circalittoral sand			Y
5	A5.27(5)	Barnacles, ascidians and tube worms on deep circalittoral sand	Y*	Y	Y
6	A5.27(51)	<i>Balanus crenatus</i> , <i>Chone duneri</i> and <i>Dendrodoa grossularia</i> on deep circalittoral sand			Y
6	A5.27(52)	<i>Balanus crenatus</i> , <i>Pomatoceros lamarki</i> and <i>Urothoe elgans</i> in deep circalittoral sand			Y
5	A5.27(6)	Sparse fauna in deep circalittoral sand		Y	
3	A5.3	Sublittoral mud	Y	Y	Y
4	A5.37	Deep circalittoral mud		Y	Y
5	A5.37(9)	Infaunal polychaetes with burrowing bivalves and amphipods in deep circalittoral mud		Y	Y
6	A5.37(91)	<i>Lagis koreni</i> and <i>Amphiura filiformis</i> with bivalves in deep circalittoral mud			Y
3	A5.4	Sublittoral mixed sediments	Y	Y	Y
4	A5.44	Circalittoral mixed sediments	Y	Y	Y
5	A5.44(7)	Infaunal polychaetes with burrowing bivalves and amphipods in circalittoral mixed sediments	Y*	Y	Y
6	A5.44(71)	<i>Abra prismatica</i> , <i>Bathyporeia elegans</i> and polychaetes in sandy mixed sediments			Y
6	A5.44(72)	<i>Abra alba</i> , <i>Urothoe elegans</i> and polychaetes in circalittoral sandy mixed sediments			Y
5	A5.44(8)	Barnacles, ascidians and tube worms on circalittoral mixed sediments	Y*	Y	Y
6	A5.44(81)	<i>Balanus crenatus</i> , <i>Chone duneri</i> and <i>Dendrodoa grossularia</i> on circalittoral mixed sediments			Y
6	A5.44(82)	<i>Dendrodoa grossularia</i> , <i>Pomatoceros lamarki</i> and barnacles on circalittoral mixed sediments			Y
6	A5.44(83)	<i>Balanus crenatus</i> , <i>Pomatoceros lamarki</i> and <i>Urothoe elgans</i> in circalittoral mixed sediments			Y
5	A5.44(A)	Sparse fauna in circalittoral mixed sediments		Y	Y
4	A5.45	Deep circalittoral mixed sediments	Y	Y	Y
5	A5.45(2)	Infaunal polychaetes with burrowing bivalves and amphipods in deep circalittoral mixed sediments	Y*	Y	Y
6	A5.45(21)	<i>Abra prismatica</i> , <i>Bathyporeia elegans</i> and polychaetes in deep circalittoral sandy mixed sediments			Y
5	A5.45(3)	Barnacles, ascidians and tube worms on deep circalittoral mixed sediments	Y*	Y	
3	A5.6	Sublittoral biogenic reefs	Y		Y
4	A5.61	Sublittoral polychaete worm reefs on sediment			Y
5	A5.611**	<i>Sabellaria spinulosa</i> on stable circalittoral mixed sediments		Y	Y
6	A5.6112	Degraded <i>Sabellaria spinulosa</i> reef with <i>Ophiothrix fragilis</i> on circalittoral sediments			Y
4	A5.6(4)	Mixed biogenic reefs of sediment			Y
5	A5.6(41)	<i>Sabellaria spinulosa</i> and <i>Mytilus edulis</i> on circalittoral mixed sediments		Y	Y

* During the course of the Humber REC 'Fine Sand' biotopes were identified in sands of varying coarseness which are not represented elsewhere in the scheme, it is therefore proposed that the EUNIS Category 'Fine Sand' is changed to 'Sand'.

** During the course of the Humber REC *Sabellaria spinulosa* reefs were identified in all biological zones sampled (circalittoral and deep circalittoral) on all substrates sampled, coarse, sand mud and mixed and it is therefore proposed that A5.611 is changed from '*Sabellaria spinulsa* on stable circalittoral mixed sediments' to '*Sabellaria spinulosa* reefs', the alternative being a further 9 new level 5 biotopes.

Table 7.2.5: Continued.

7.3 Trophic significance of the Humber REC study area

The Humber REC study area, and the wider southern North Sea, are important areas of marine production. The marine food web supports commercially significant fisheries and provides food for top predators in the food chain such as fish, birds and mammals. Important commercial fish species such as cod, whiting, seabass, haddock, plaice, common sole, dab and rays and several crustacean species have been recorded in the REC study area (see Section 2.10). The Humber Estuary is a highly productive area and also attracts large numbers of waterfowl, seabirds and seals. Although the Estuary does not fall within the Humber REC study area it is likely to have an influence on production in the wider region and the bird species are likely to use the area to forage.

Small fish such as sandeels are particularly important prey items for several bird species and the importance of benthic invertebrate communities to higher trophic levels, including to commercial fisheries, is well recognised. Benthic invertebrates often provide the link between pelagic production in the water column, the benthos and higher trophic levels through the processing of organic matter that settles to the seabed. This energy is then available to higher trophic levels as benthic, demersal and pelagic species prey on benthic invertebrates.

Several important commercial fish species, such as the lesser sandeel (*Ammodytes marinus*), sprat (*Sprattus sprattus*) and capelin (*Mallotus villosus*) are known to be target prey for seabirds in the Humber region (Furness & Tasker 2000; Bull *et al.* 2004). Fisheries in the area therefore exert an influence on the distribution and behaviour of seabird feeding and population dynamics, through indirect and direct trophic interactions and mortality from fishing gear (Garthe, Camphuysen & Furness 1996; Kirby, Holmes & Sellers 1996; Furness & Tasker 2000; Votier, Heubeck & Furness 2008; Frederiksen *et al.* 2006).

Many marine fishes are opportunistic predators and will readily switch feeding preferences in space as well as time. Thus, most fish species have no highly developed preference for a particular food source and show great trophic adaptability, taking advantage of whatever food source happens to be abundant. Feeding habits may change on a seasonal or even interannual basis and several fish species have significant ontogenetic shifts in diet. For example, the larval and juvenile stages of cod, haddock and whiting feed

Common name	Species name	Most common prey items	Refs
Cod	<i>Gadus morhua</i>	<i>Crangon</i> spp.	1, 2
		<i>Pandalus</i> spp.	
		Crustaceans	
		Sandeels	
		Fish (incl. dragonets and gadoids)	
Whiting	<i>Merlangius merlangus</i>	Sandeels	1,3
		Fish	
		Euphausiids	
		<i>Crangon</i> spp.	
		Crabs	
		Polychaetes	
Haddock	<i>Melanogrammus aeglefinus</i>	Sandeels	1
		Crabs	
		Polychaetes	
		Brittle stars	
		Starfish and urchins	
European plaice	<i>Pleuronectes platessa</i>	Polychaetes	1,3
		Sandeels	
		Bivalves	
		Crustaceans (especially mysids)	
		Brittlestars	
Dover sole	<i>Solea solea</i>	<i>Crangon</i> spp.	1,3
		Polychaetes (especially <i>Pectinaria koreni</i> and <i>Sabellaria spinulosa</i>)	
Common dab	<i>Limanda limanda</i>	Brittlestars	1,3
		Crabs	
		Polychaetes (incl. <i>Sabellaria spinulosa</i>)	
		Sandeels	
Lemon sole	<i>Microstomus kitt</i>	Polychaetes	1
		Gastropods	
		Necklace shells	
		Crabs	
Raja rays	<i>Raja clavata</i>	<i>Crangon</i> spp.	1
		<i>Pandalus</i> spp.	
		Sandeels	
		Crabs	
		Euphausiids & mysids	

Table 7.3.1: The most common prey groups, for a number of commercial fish species, as identified by fish stomach content analysis (References: 1. Pinnegar, 2009, DAPSTROM North Sea data; 2. Alderstsein & Welleman, 2003; 3. Pearce, 2008).

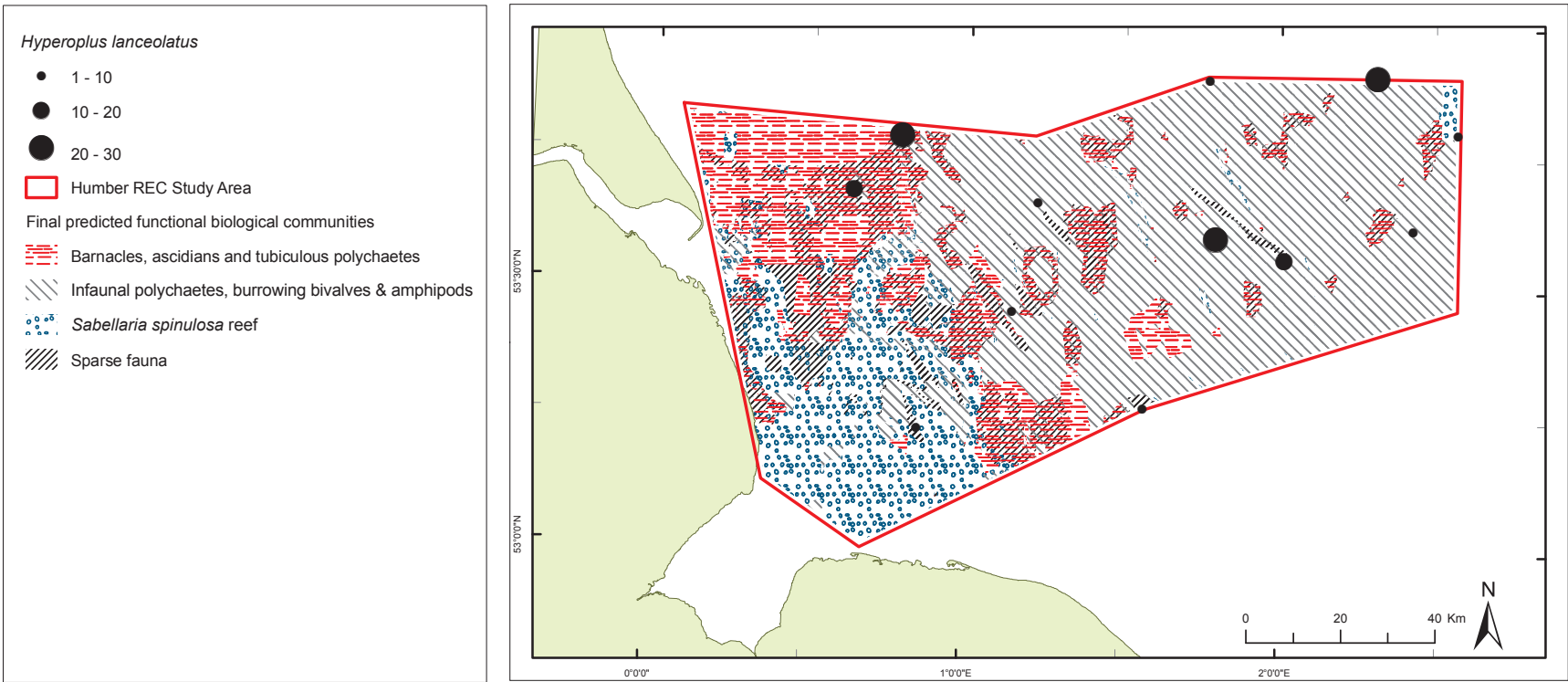


Figure 7.3.1: Distribution and abundance of *Hyperoplus lanceolatus* in 2 m beam trawls (5 mm mesh size) from the Humber REC study area.

predominantly on copepods and euphausiids whilst in the water column, switching to benthic invertebrate species such as the brown shrimp *Crangon* spp. as a bottom dwelling adult.

Although the feeding strategy of many fish reflect the abundance of prey items available, there are still some observed differences between broad groups of fish. For example, at a number of aggregate dredge sites the majority of fish species investigated were found to be benthic invertebrate feeders with a strong preference for crustaceans, especially crabs. In contrast flat fish, such as plaice, Dover sole, dab and lemon sole were found to be more likely to feed on polychaetes (Pearce 2008).

Data on fish stomach contents comes from two sources: the Cefas DAPSTROM (Integrated Database & Portal for Fish Stomach Records) records and an ALSF funded project looking at the significance of benthic communities for higher trophic levels at a number of aggregate dredge sites (Pearce, 2008).

Crustaceans appear to be the most significant dietary item for all seven fish species for which sufficient data was available (cod,

whiting, haddock, plaice, common sole, dab, lemon sole and thornback ray). Crabs, shrimp including the brown shrimp *Crangon* spp. and the pink shrimp *Pandalus*, polychaetes, sandeels and brittlestars are the most common prey items for these fish. However, there is often an element of bias in stomach content analysis, where the hard parts of prey items are more likely to remain as identifiable remains. Thus, groups such as crustaceans, echinoderms and polychaetes, with hard exoskeletons or chaete may be over-represented in stomach contents.

Sandeels

Sandeels are important prey for many top marine predators, including marine mammals such as grey seals and harbour seals, harbour porpoise and important commercial fish species, such as cod, whiting, haddock and mackerel (Table 6.8.1.). They are also prey for several seabird species such as terns, guillemots and puffins. Sandeels also support the largest industrial fishery in the North Sea, with recent annual landings in the region of 0.5–1 million tonnes. Of the five species of sandeels inhabiting the North

Sea, the lesser sandeel, *Ammodytes marinus* is the most abundant and comprises over 90% of sandeel fishery catch.

Like other short lived species, sandeel stocks can be highly variable, in time and space, as recruitment is dependent on many factors. High natural mortality also makes it difficult to assess stocks of this species.

With so many predators dependent on sandeels, the level of exploitation has raised concerns regarding the impact on marine food webs (Holland *et al.* 2005). Many sandeel fishing grounds are close to seabird colonies, and there is considerable overlap in the distribution of sandeels, seabirds feeding at sea, and industrial fishing activity (Wright & Begg 1997). These conflicts have resulted in increasing concern about the potential impact of sandeel fishing on seabirds (Furness & Tasker 2000) and some research has observed that declines in seabird breeding success appeared to be associated with increased sandeel fishing activity nearby (Monaghan *et al.* 1989). ICES recommend that in areas where stocks have been depleted fishing should be closed to allow recovery.

There were no *Ammodytes* species sampled during the Humber REC benthic survey and only low numbers of *Hyperoplus lanceolatus* (Figure 7.3.1). The sampling gear, a 2 m beam trawl with a 5 mm mesh size, is thought to be suitable for sandeel capture, and although there may be some variation in catch rates the low numbers are thought to be indicative of the impact of industrial scale fishing for sandeels in the North Sea.

Availability of suitable habitat is a key constraint to the distribution of sandeels. They are known to prefer medium to coarse sand and have been shown to avoid areas with high levels of coarse gravel, fine gravel, and silts (Holland *et al.* 2005). Sandeels were observed in only 40 % of the beam trawls (12 of the 30 trawls) deployed across the area. Where sandeels were observed they were sampled in low abundance with an average of 5 individuals per trawl. These samples were collected from areas of sand and gravelly sand primarily in Functional Biological Community 2 'Infaunal polychaetes with burrowing bivalves and amphipods' and in 'Sparse Fauna' communities (FBC 4). Thus, it appears that there is no particular area within the Humber REC that is especially important for sandeels.

Brown Shrimp, *Crangon crangon*

The brown shrimp (Figure 7.3.2) is a key prey item for several commercially important fish species (Table 6.7.1) as well as being a species subject to a large fishery in the southern North Sea. They are also consumed by seabirds especially gulls and terns, species which are known to use the area for foraging (see Section 2.8).

As an opportunistic omnivore feeder of a wide range of plant and animal material *Crangon* spp. represent an important link between the benthos and several fish species. *Crangon* will consume polychaetes, molluscs and small arthropods such as mysids and amphipods.

The distribution of brown shrimp in the Humber REC area is fairly patchy, with the species occurring in 77% of trawls but, with the exception of 4 trawls (Figure 7.3.3), they were present in very low abundance (less than 30 individuals per trawl). Fisheries landings data shows that the catch of *Crangon* in the North Sea has not declined in the past 20 years. There is, however, no historical data available for catches in the Humber region.



Figure 7.3.2: The brown shrimp, *Crangon crangon*.

Only one trawl, no T86, captured significant numbers of *Crangon*, with over 2300 individuals sampled. The next largest haul was only 50 animals. Trawl 86 took place in an area of the Humber close to the deep waters of Botney Cut, where there is a dominance

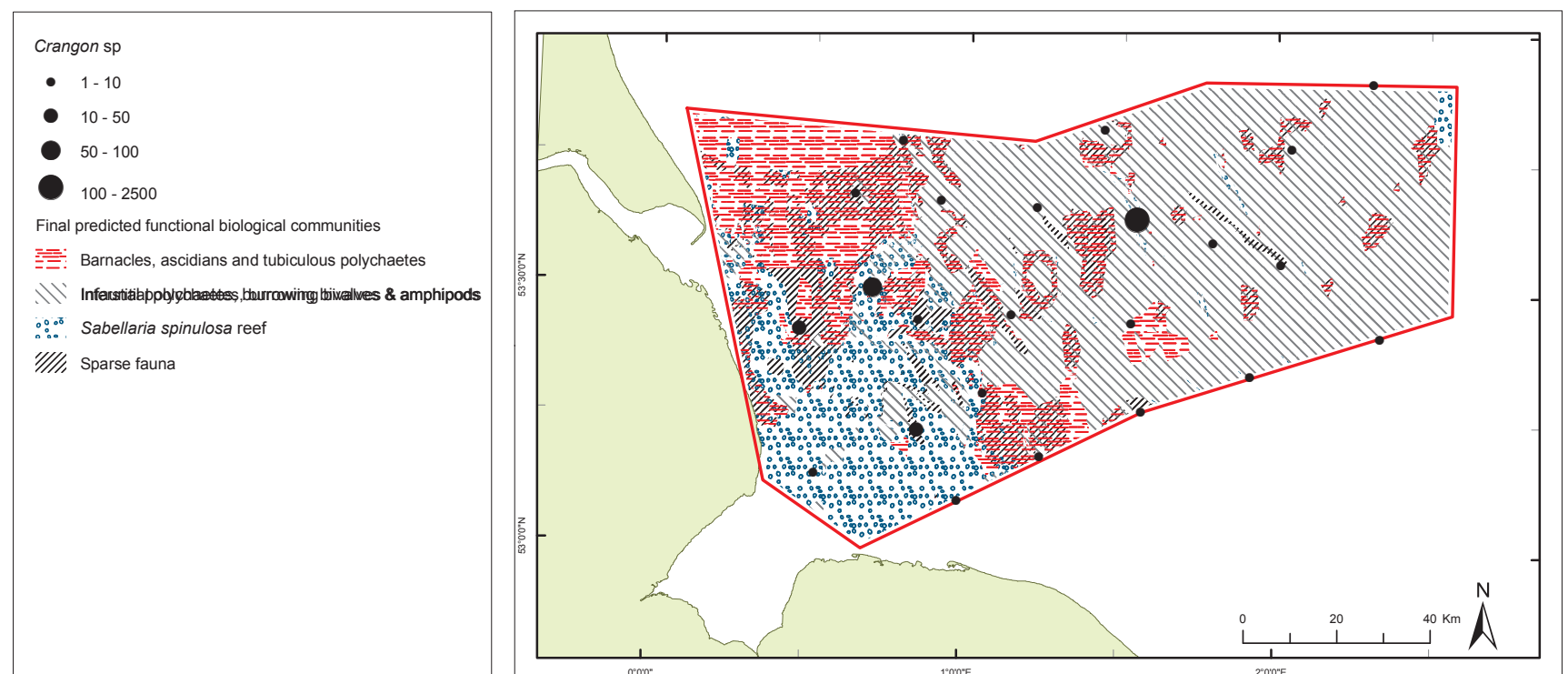


Figure 7.3.3: Distribution and abundance of *Crangon* spp. in 2 m beam trawls (5 mm mesh size) taken across the Humber REC area.

of muddy sediments. The presence of a high density of *Crangon* suggests this area is highly productive although it known to be trawled by fishing only relatively lightly (Jennings *et al.* 2000). The Functional Biological Community mapped for this area is Group 2 'Infaunal polychaetes and burrowing bivalves and amphipods' which suggests that the area may represent good feeding grounds for *Crangon*.

Pink Shrimp - *Pandalus montagui*

Pink shrimp, *Pandalus* spp., (Figure 7.3.4) are a common prey item for a number of fish species and several studies show that where densities are high the incidence in the stomach of fish, such as cod, is also high (Ponomarenko & Yaragina, 1984). *Pandalus* was observed in just over half of the trawls but was present in high abundance (>200 individuals) in only 6 trawls. High abundance was found particularly in areas where Functional Biological Community 3 'Sabellaria reefs' (Figure 7.3.5). *Pandalus montagui* is known to feed on *Sabellaria spinulosa* and high abundances of this species have been observed in other areas where reef is present. At some trawl stations within Functional Biological Community 1 'Barnacles, ascidians and tubicolous polychaetes' the abundance of *Pandalus* was also fairly high.



Figure 7.3.4: The pink shrimp, *Pandalus montagui*.

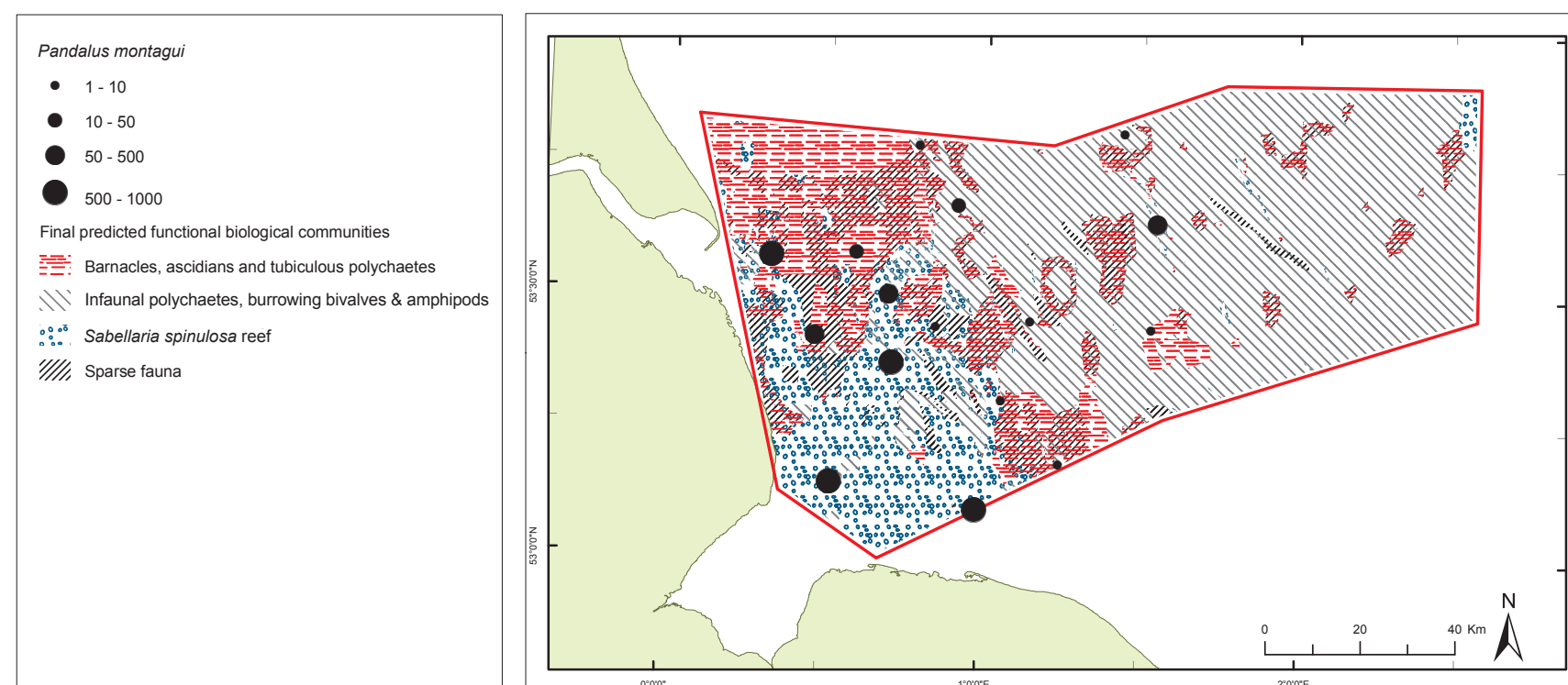


Figure 7.3.5: Distribution and abundance of *Pandalus montagui* in 2 m beam trawls (5 mm mesh size) taken across the Humber REC area.

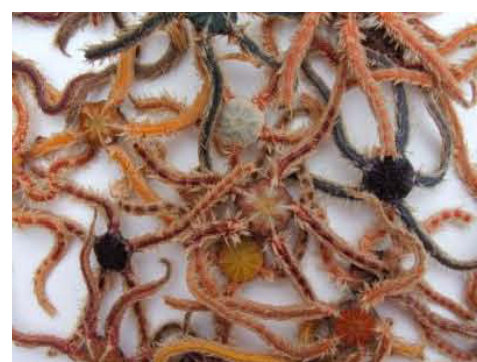


Figure 7.3.6:
The brittlestars
Ophiothrix fragilis
and *Ophiura* sp.

Brittlestars

Although brittlestars (Figure 7.3.6) are commonly found in the stomachs of haddock, plaice and dab, it appears from analysis of stomach contents of fish collected from aggregate dredge sites that the percentage contribution to diet is very small (Pearce, 2008). Brittlestars were not particularly widespread within the Humber REC study area being sampled at only 16 of the 30 trawls (Figure 7.3.7). Where they were present they were recorded in low abundance with the exception of T86 where a brittle star bed was sampled in the Sole Pit area where the sediments are fairly muddy. In this one trawl alone, 6400 brittlestars were sampled, with a 85:15 split between *Ophiothrix fragilis* and *Ophiura* spp.

Crabs

Crabs, and crustaceans generally, form an important part of the diet for many fish and bird species. Several crab species are recorded throughout the area (Figure 7.3.8) but there does not appear to be any area that is especially important for this food source.

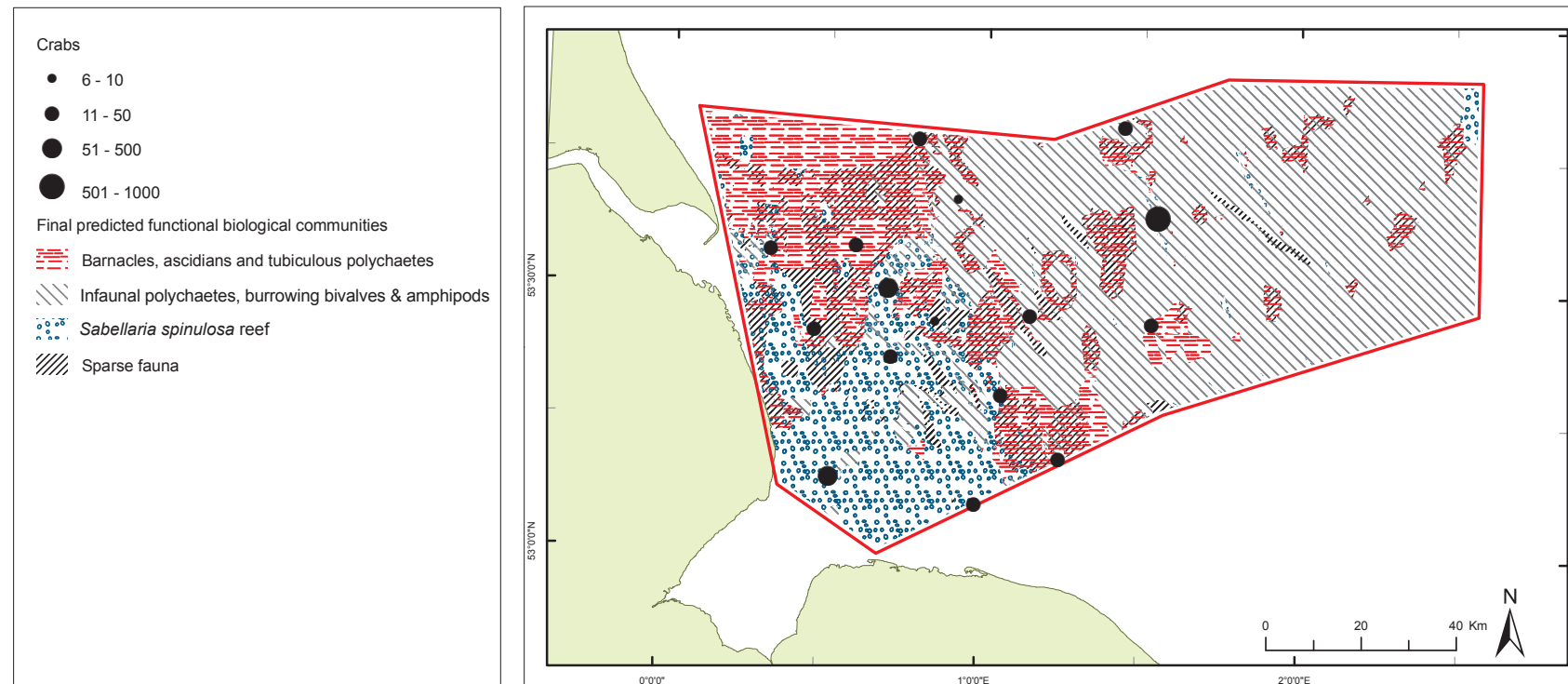


Figure 7.3.7: Distribution and abundance of brittlestars in 2 m beam trawls (5 mm mesh size) taken in the Humber REC area.

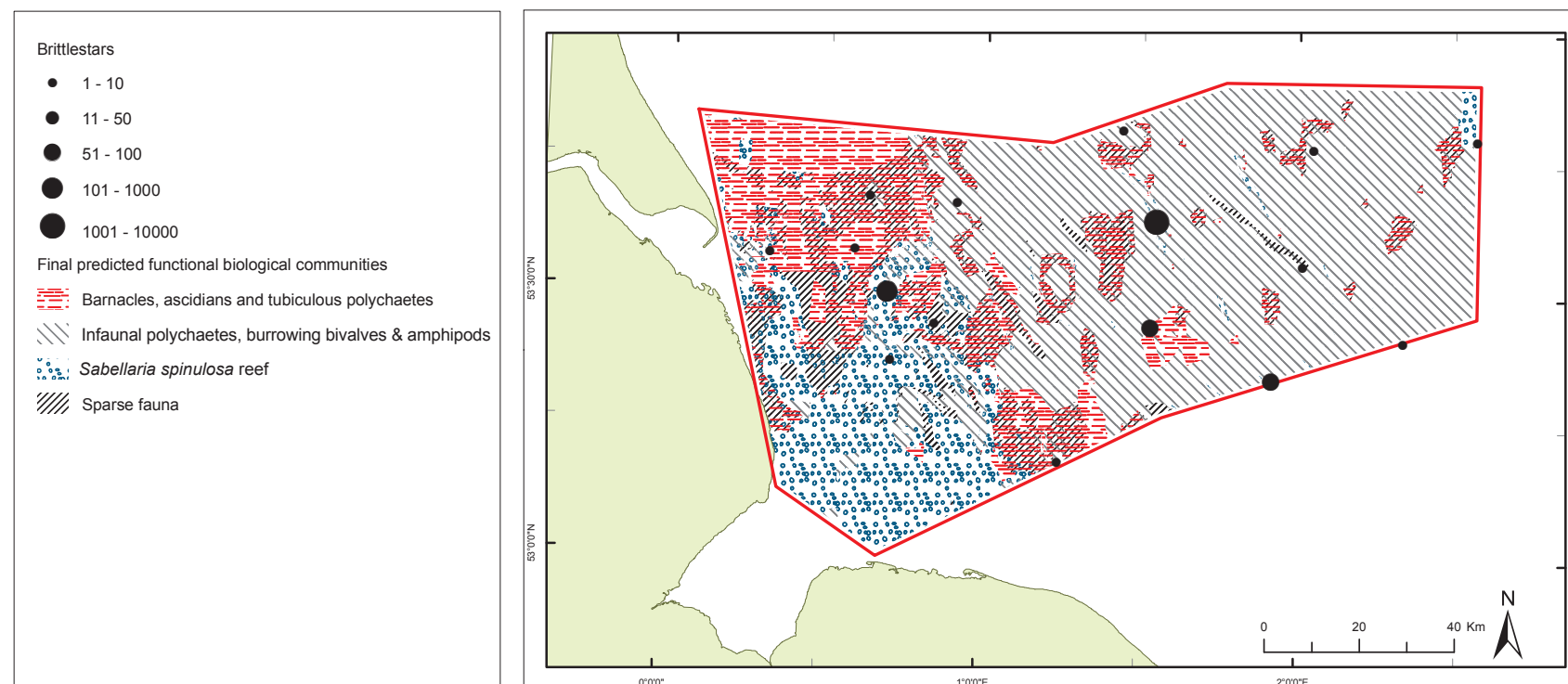


Figure 7.3.8: Distribution and abundance of crabs in 2 m beam trawls (5 mm mesh size) taken across the East Coast REC area.

8 Features of Stakeholder Interest — 1

8.1 Tunnel Valleys

Within the Humber REC study area there are a series of arcuate sub-linear seabed depressions with limited sediment infill, collectively called tunnel valleys (Figure 8.1.1). The tunnel valleys radiate outward from the mapped palaeo-ice margin of the Devensian (Weischelian) glaciations, reaching depths of up to 100m. Although the precise process which led to the formation of these features is unclear, their orientation suggests that they were formed either by sub-glacial fluvial activity or ice dam breakouts (Jakulhaups) associated with the receding ice sheet. Recent

research on buried equivalents of the tunnel valleys which are found further north have found that such valleys have resulted from steady-state sub-glacial fluvial erosion and subsequent backfill beneath a receding ice sheet (Huuse *et al.* 2000; Praeg, 2003). The absence of sediment infill in the southern North Sea tunnel valleys is not well understood, but is thought to be due to either erosion during post-glacial sea-level rise, or an original lack of sediment infill. The amplitude of modern tidal forces now prohibits sediment deposition giving rise to these unique seabed features (Pingree and Griffiths, 1979; Proctor *et al.* 2001).

Sporadic observations of *Sabellaria spinulosa* aggregations along the western slopes of the Silver Pit, extending down towards the Lynn Knock and Inner Dowsing area, have been reported in environmental impact assessments for adjacent marine developments over the course of many years (Emu, 2005, MES, 2003, MES, 2009). The consistency of these records suggests that the Silver Pit supports a relatively persistent *S. spinulosa* reef which could qualify as an Annex I habitat under the EC Habitats Directive. In order to study the association between *Sabellaria spinulosa* and the Silver Pit in more detail, a focused survey covering a cross section of the valley was undertaken (Figure 8.1.1). A cross section of the Sole Pit was also surveyed (Figure 8.1.1) to provide a comparison with the Silver Pit and to investigate the hypothesis that further *Sabellaria spinulosa* reefs might be associated with other, previously un-surveyed tunnel valley features. Comprehensive side-scan sonar and multibeam data were collected from the two focused study areas and were subsequently ground truthed with biological sampling in order to investigate the ecological significance of these two tunnel valley features.

The Silver Pit

The Silver Pit is the largest of the tunnel valley features that exists within the Humber REC study area, running roughly north to south for over 50km and reaching depths of almost 100 m (Figure 8.1.1). The focused study area is located in the centre of the valley and has approximate dimensions of 3.5 km x 2 km, incorporating the shallow seabed through which the valley was cut-out, the valley flanks, and the valley floor (Figure 8.1.2).

Beyond the valley itself the margin sediments are typically sandy gravels, although there is a larger mud component on the eastern margins. The sandy gravel deposits extend down the slopes of the valley becoming increasingly sandy towards the base of the slope. The subtle shifts in sediment composition across the Silver Pit are associated with equivalent shifts in the biological communities although the feature as a whole could be characterised as supporting a relatively rich faunal complement including a diverse range of epifauna. The most well developed examples of *Sabellaria spinulosa* reef were found on the western flanks of the Silver Pit, although a less distinct carpet of *S. spinulosa* was also found to

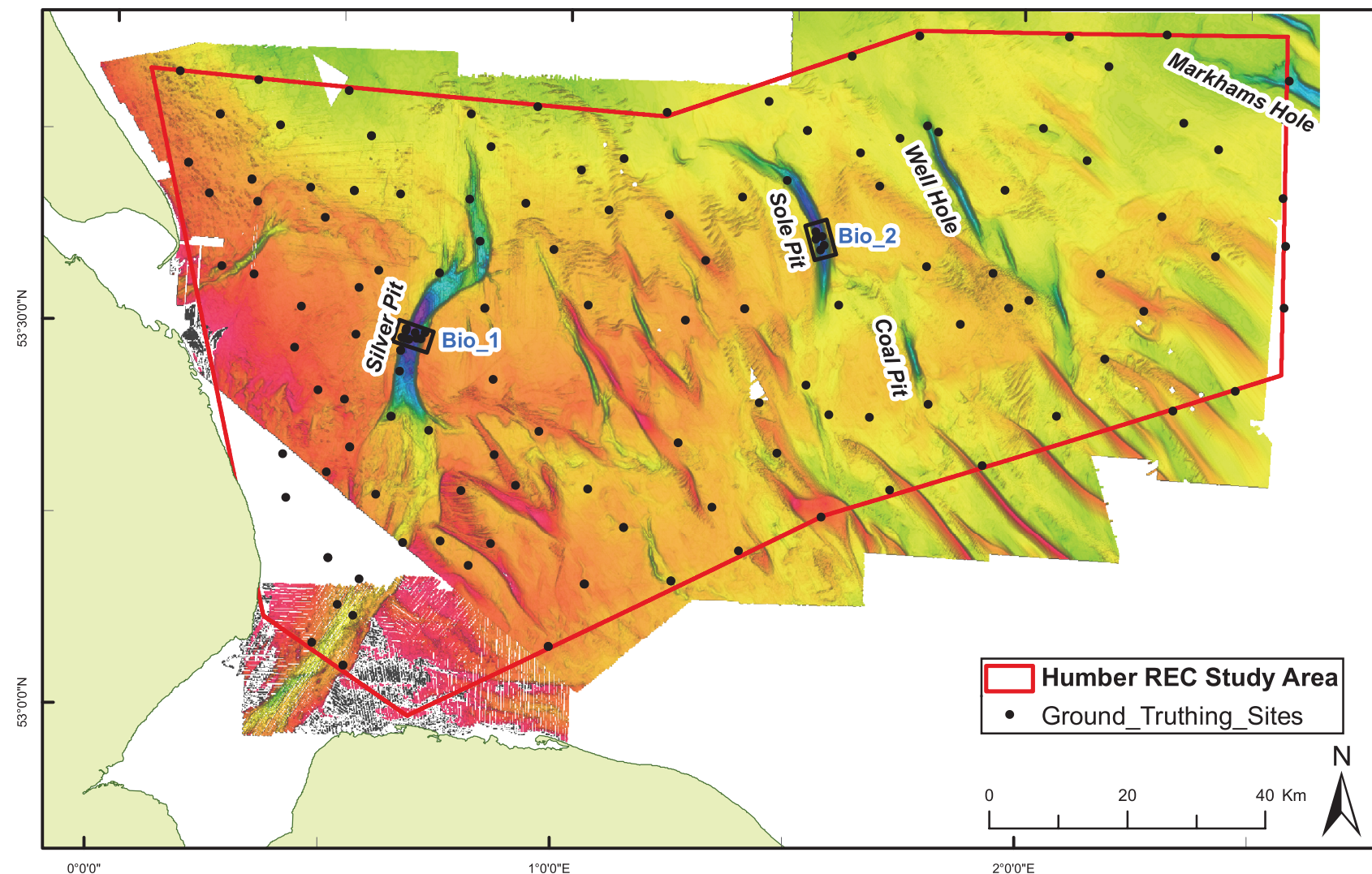


Figure 8.1.1: Tunnel valleys in the Humber REC study area. Also shown are the two focused study areas.

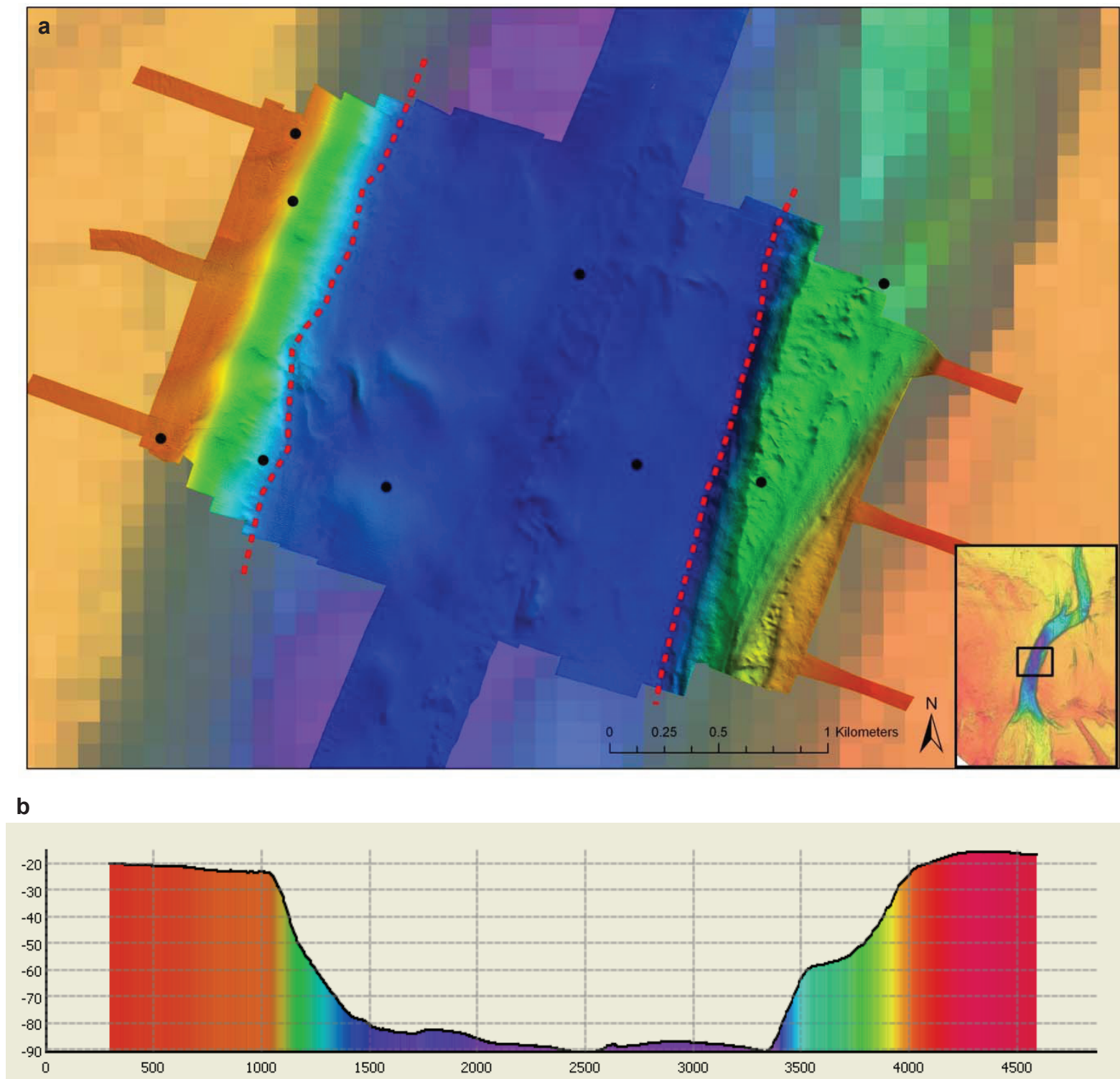


Figure 8.1.2a: Bathymetric map of the Silver Pit focused study site and surrounding area. Stations sampled for the biological analysis of the Silver Pit are also shown and the boundaries between the valley floor and the slope edges is delineated by red dashed lines. Shade source 315° - NW. Single beam echo sounder data © British Crown and Sea Zone Solutions Ltd. 2008. All rights reserved. Data Licence 052008.012. **b)** Depth profile of the Silver Pit.

occur on the tunnel floor. *Sabellaria spinulosa* was virtually absent from the eastern flanks and was replaced by other epifaunal species including ascidians and hydroids. These three broad geomorphological features and the marine life which they support are described in more detail overleaf.

The Western Slope

Side-scan sonar data collected across the western flanks of the Silver Pit revealed an irregular, topographically distinct texturing

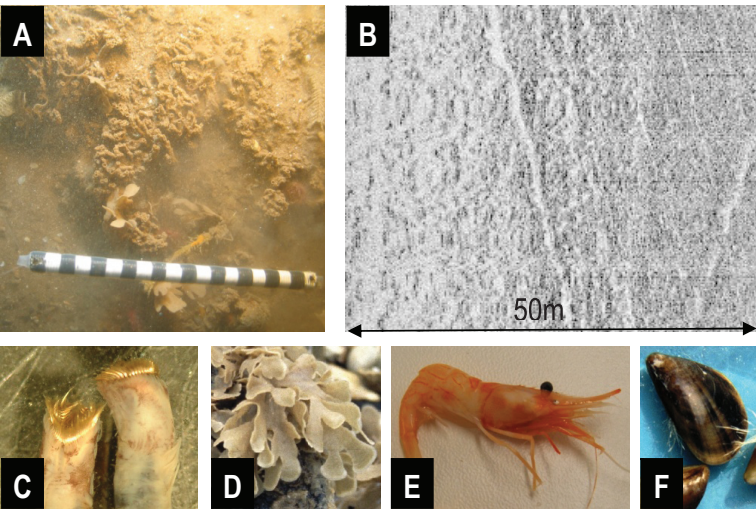


Figure 8.1.3: (A) Digital still image, (B) side-scan sonar signature and fauna associated with the western slopes of the Silver Pit. (C) *Sabellaria spinulosa*, (D) *Flustra folicea*, (E) *Pandalus montagui* (F) *Mytilus edulis*.

Species	Av.Abund
<i>Sabellaria spinulosa</i>	277.6
<i>Hiatella arctica</i>	23.2
ASCIDIACEA	11.2
Golfingiidae	10.2
<i>Lumbrineris gracilis</i>	7.8
<i>Pholoe baltica</i>	5
Mytilidae	3.6
<i>Galathowenia oculata</i>	2.6
<i>Laonice bahusiensis</i>	1.8

Table 8.1.1: Top ten characterising species of the western slopes of the Silver Pit and their average abundance across 5 samples.

Average No. Species	171
Average Abundance	517
Shannon Weiner's Diversity (H' (Loge))	2.55
Taxonomic Distinctness (Δ^*)	90.55

Table 8.1.2: Summary of the diversity of benthic fauna associated with the western slopes of the Silver Pit.

(Figure 8.1.3 B) which has been reported to be indicative of biogenic reef built by *Sabellaria spinulosa* (MESL, 2009, MESL, 2006 and MESL, 2005). This was corroborated by the seabed images taken to groundtruth the area which revealed well developed reef structures (Figure 8.1.3 A). The extent of this texturing across the slope confirms the presence of an extensive reef complex as had been suggested by earlier surveys of this area (Tappin *et al.* 2009).

The western slopes of the Silver Pit are numerically dominated by the Ross worm, *Sabellaria spinulosa* which is present at an average density of 278 0.1m⁻² (Table 8.1.1). A mix of infaunal species (including infaunal polychaetes, burrowing bivalves, amphipods and sipunculids) and epifaunal species (including sea squirts, hydroids, bryozoans and mussels) were also observed in the grab samples taken on the western slopes of the Silver Pit, giving rise to a taxonomically diverse faunal assemblage (Table 8.1.2). Seabed images of the reef also revealed an association with larger crustaceans including the pink shrimp *Pandalus montagui*, which are too mobile to be sampled with the grab. This confirms earlier suggestions that this reef complex may be important in supporting a commercially important pink shrimp population (Warren & Sheldon, 1967).

The blue mussel *Mytilus edulis* was also found to be associated with the reefs of the western slopes, present in similar densities at some stations. Successions between Sabellariid reef and mussel beds have been widely reported in the literature (Cunliffe *et al.* 1994; Pohler, 2004; Reise & Shubert, 1987; Riesen & Reise, 1982) and it would seem that there is such a strong overlap in the environmental niches occupied by these animals that even a slight shift in the conditions can alter the community by favouring one group or the other. Where *S. spinulosa* and *M. edulis* were present in similarly high numbers we have suggested that this

community be assigned a new Eunis Level 4 biotope complex of mixed biogenic reef (refer to biotope Section 7.1.2). In practice it is likely that there will be an ongoing cyclical succession between *Sabellaria spinulosa* reefs (A5.611) and *Mytilus edulis* beds (A5.625) in this area.

The Valley Floor

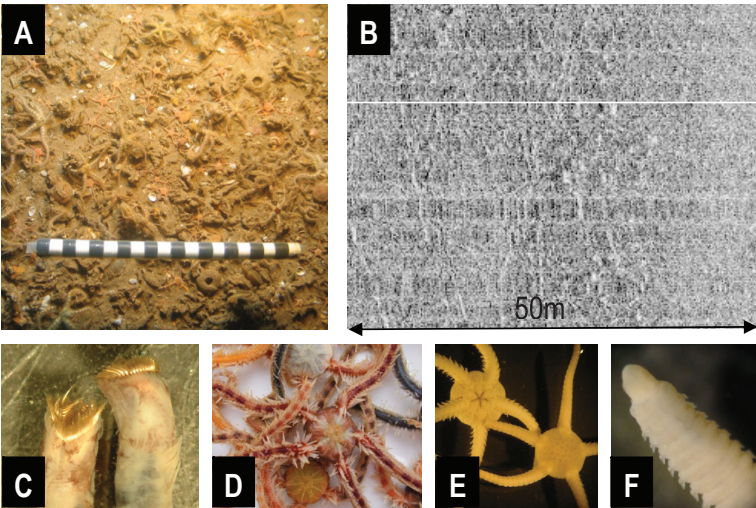


Figure 8.1.4: (A) Digital still image, (B) side-scan sonar signature and fauna associated with the floor of the Silver Pit. (C) *Sabellaria spinulosa*, (D) *Ophiothrix fragilis*, (E) *Ophiura albida* (F) *Lumbrineris gracilis*.

Species	Av.Abund
<i>Sabellaria spinulosa</i>	196
<i>Lumbrineris gracilis</i>	21
<i>Ophiura albida</i>	16.67
<i>Mytilus edulis</i>	15.67
<i>Ophiothrix fragilis</i>	15
<i>Jupiteria minuta</i>	14
<i>Mediomastus fragilis</i>	12.33
<i>Spiophanes kroyeri</i>	10.33
<i>Pholoe baltica</i>	9
<i>Urothoe elegans</i>	8.67

Table 8.1.3: Top ten characterising species of the floor of the Silver Pit and their average abundance across 3 samples.

Average No. Species	118
Average Abundance	478
Shannon Weiner's Diversity (H' (Loge))	2.97
Taxonomic Distinctness (Δ^*)	86.72

Table 8.1.4: Summary of the diversity of benthic fauna associated with the floor of the Silver Pit.

Side-scan sonar data collected across the floor of the Silver Pit revealed a similarly irregular, but less distinct texturing (Figure 8.1.4 B) as that observed on the western slopes. Seabed images taken across the area revealed a relatively continuous carpet of *Sabellaria spinulosa* associated with high numbers of brittle stars (Figure 8.1.4 A).

The floor of the Silver Pit is again numerically dominated by the Ross worm, *Sabellaria spinulosa* (Table 8.1.1) despite the absence of erect reef structures. The fauna associated with this carpet of *S. spinulosa* are similar to the fauna observed on the western slopes with the notable addition of the brittle stars, *Ophiothrix fragilis* and *Ophiura albida*. Seabed images confirmed the presence of dense brittle star beds overlying *S. spinulosa* aggregations. Brittle stars are filter feeders and it has been postulated that dense aggregations could inhibit growth and recruitment of *S. spinulosa* reef through their active removal of larvae from the water column and competition for food (George & Warwick, 1985).

The valley floor supports a benthic community which is similar in composition and diversity to the community identified on the western slopes of the Silver Pit (Table 8.1.4). It has therefore also been described as *S. spinulosa* reef for the purpose of this characterisation (Eunis Biotope A5.611).

The Eastern Slope

The eastern slope of the Silver Pit gave a very different acoustic signature to those observed on the western slopes and valley floor which was generally more smooth in appearance (Figure 8.1.5 B). Seabed images taken across the area revealed a sandy mixed sediment with some epifauna but a notable absence of *Sabellaria spinulosa* aggregations (Figure 8.1.5 A).

The eastern slopes of the Silver Pit are characterised by a diverse mix of infaunal and epifaunal species (Table 8.1.6). Whilst

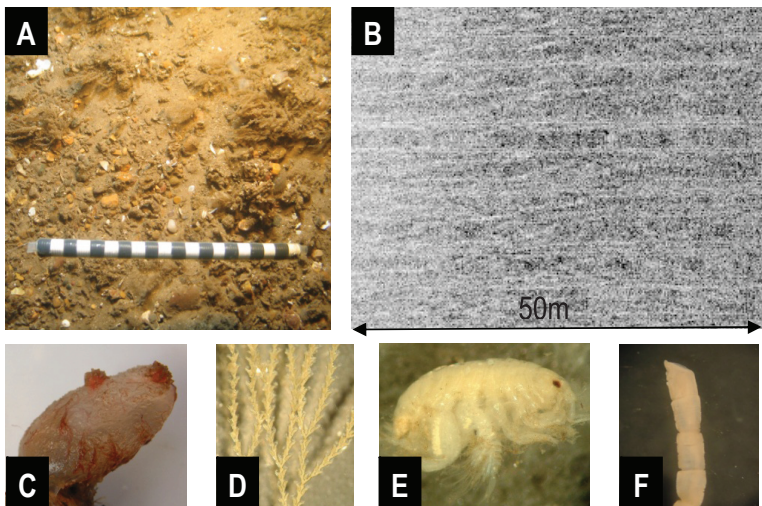


Figure 8.1.5: (A) Digital still image, (B) side-scan sonar signature and fauna associated with the eastern slopes of the Silver Pit. (C) *Ascidacea* (D) *Setularia cupressina*, (E) *Urothoe elagans* (F) *Eucylmene* sp.

Species	Av.Abund
ASCIDIACEA	59.5
<i>Urothoe elegans</i>	38.5
<i>Sabellaria spinulosa</i>	20.5
<i>Spiophanes kroyeri</i>	18.5
<i>Euclymene oerstedii</i>	16.5
<i>Polydora caulleryi</i>	10
<i>Pholoe baltica</i>	6.5
<i>Lumbrineris gracilis</i>	4.5
<i>Clymenura</i>	4
Polynoidae	3.5

Table 8.1.5: Top ten characterising species of the eastern slopes of the Silver Pit and their average abundance across 2 samples.

Average No. Species	171
Average Abundance	405
Shannon Weiner's Diversity (H' (Loge))	3.88
Taxonomic Distinctness (Δ^*)	93.62

Table 8.1.6: Summary of the diversity of benthic fauna associated with the eastern slopes of the Silver Pit.

Sabellaria spinulosa do not dominate this area, they are still present in small numbers (Table 8.1.5). Other taxa present include high numbers of the burrowing amphipod *Urothoe elegans* and a number of infaunal polychaete species. Sea squirts (Ascidacea) were very abundant in the grab samples as well as in the seabed images along with other epifauna including hydroids and bryozoans. The overall diversity of the eastern slopes of the Silver Pit was found to be higher than both the western slopes and the valley floor despite there only being two samples taken from this area.

The Sole Pit

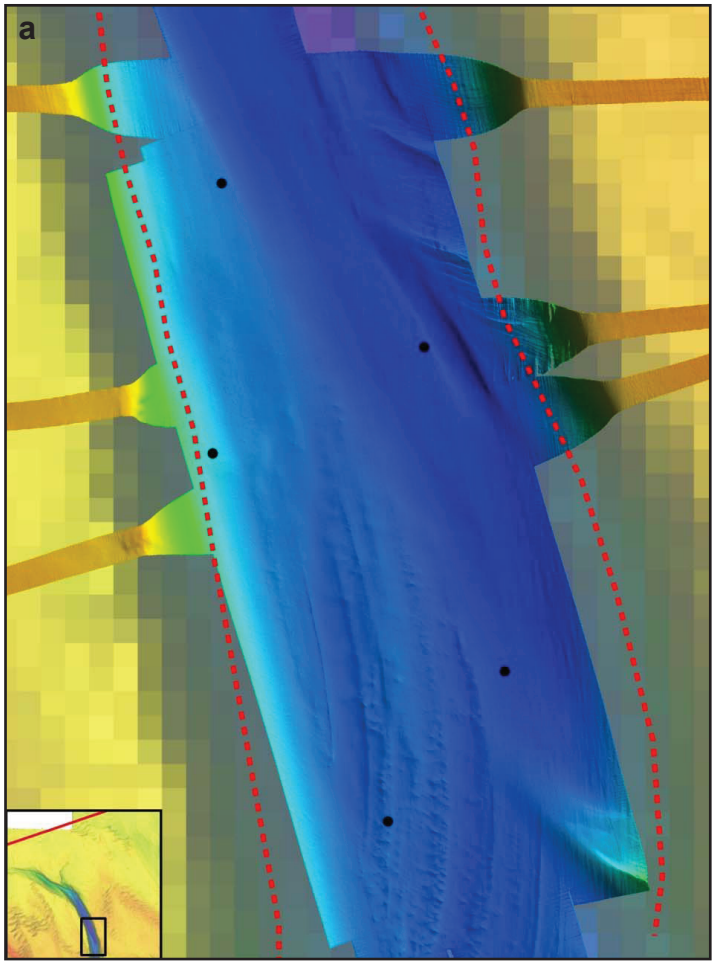
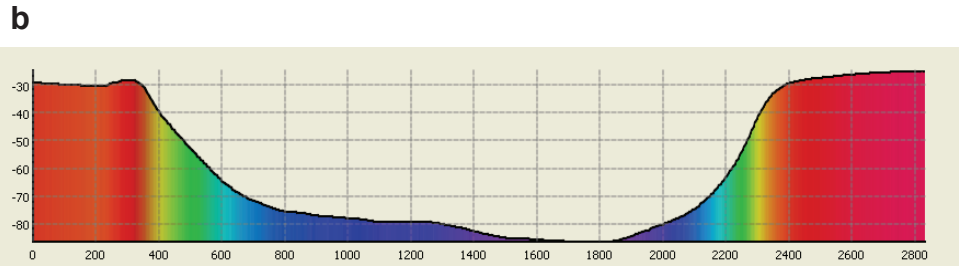


Figure 8.1.6a: Bathymetric map of the Sole Pit focused study site and surrounding area. Stations sampled for the biological analysis of the Sole Pit are also shown and the boundaries between the valley floor and the slope edges is delineated by red dashed lines. Shade source 315° - NW. Single beam echo sounder data © British Crown and Sea Zone Solutions Ltd. 2008. All rights reserved. Data Licence 052008.012.



The Sole Pit is the second largest of the tunnel valley features that exists within the Humber REC study area, approximately 30km in length and reaching depths of almost 90 m (Figure 8.1.1). Despite its size the Sole Pit has not previously been surveyed in this manner because it is located a great distance from any marine activity. As a means of investigating the similarities between this feature and the Silver Pit a focused study area was located in the centre of the valley with approximate dimensions of 3.5 km x 1.5 km, incorporating the shallow seabed through which the valley was cut-out, the valley slopes (flanks), and the valley floor (Figure 8.1.6).

The sediments of the Sole Pit have a greater proportion of sand than those of the Silver Pit. The valley margins and upper slopes are comprised of gravelly sands and the lower slopes and valley floor are comprised of slightly gravelly muddy sands. Survey constraints meant that only six samples were collected from the Sole Pit and all of these were taken from the valley floor meaning that only a rudimentary comparison can be made between the fauna associated with the two tunnel valleys. The faunal communities were however found to differ markedly, reflecting the composition of the sediments. The most abundant species recorded from the Sole Pit was the bivalve, *Abra alba* with over 4000 individuals recorded from six grab samples. Other abundant fauna included the brittle star *Amphiura filiformis* and the polychaete *Anobothrus gracilis*. The environmental conditions of the Sole Pit and the fauna it supports are described in more detail overleaf.

The Valley Floor

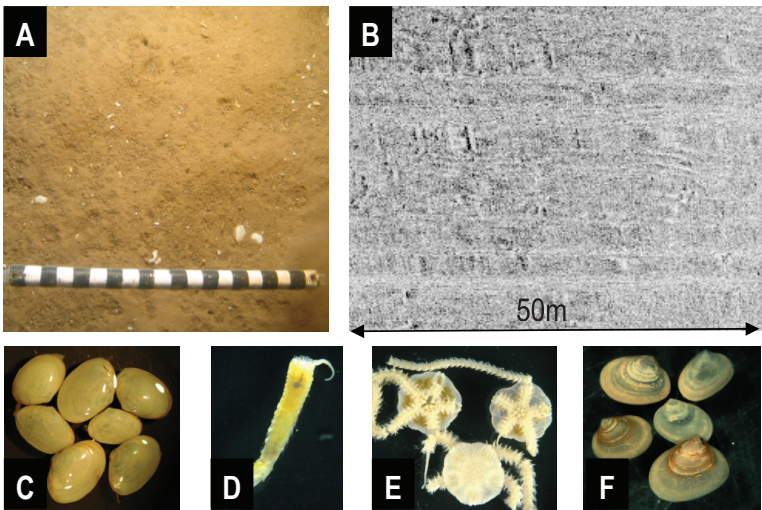


Figure 8.1.7: (A) Digital still image, (B) side-scan sonar signature and fauna associated with the floor of the Sole Pit, (C) *Abra alba*, (D) *Anobothrus gracilis*, (E) *Amphiura filiformis*, (F) *Mysella bidentata*.

Species	Av.Abund
<i>Abra alba</i>	797.8
<i>Amphiura filiformis</i>	32.4
<i>Mysella bidentata</i>	21.8
<i>Anobothrus gracilis</i>	19.8
<i>Pholoe baltica</i>	13
<i>Notomastus latericeus</i>	12.6

Table 8.1.7: Top six characterising species of the floor of the Sole Pit and their average abundance across 6 samples.

Average No. Species	171
Average Abundance	1125
Shannon Weiner's Diversity (H' (Loge))	1.74
Taxonomic Distinctness (Δ^*)	93.80

Table 8.1.7: Summary of the diversity of benthic fauna associated with the floor of the Sole Pit.

The floor of the Sole Pit gave a very different acoustic signature to those observed on the Silver Pit which was generally much more smooth in appearance (Figure 8.1.7 B). Seabed images taken

across the area revealed a muddy sand substrate with little to no epifauna (Figure 8.1.6 A).

The floor of the Sole Pit is numerically dominated by the bivalve *Abra alba* which is present at an average density of 798 0.1m⁻² (Table 8.1.7). The bivalve *A. alba* is a characteristic inhabitant of muddy fine sand and is often particularly abundant at water depths of around 20 m (Tebble, 1976). It is unusual to find such high densities at these depths (70-90 m) although this may be because these deep valleys have not previously been studied in any detail. *Abra alba* has a widespread distribution around the UK and much of Europe and is often associated with highly diverse and abundant communities (Van Hoey *et al.* 2004). Dense aggregations, as are seen here, are likely to be of some ecological significance, possibly serving as a food resource for demersal fish (Degraer *et al.* 1999). The benthic community sampled from the floor of the Sole Pit is similar in its diversity to benthic community sampled from the most developed *Sabellaria spinulosa* reefs of Silver Pit. The density of benthic animals though is almost double (Table 8.1.7).

Other species which were characteristic of the floor of the Sole Pit include the brittle star *Amphiura filiformis* and its coinhabitant the bivalve *Mysella bidentata* (Josefson, 1998). *Amphiura filiformis* is a burrowing brittle star which favours muddy environments, where its body, and all but the top centimetre of its arms, remain below the surface (Nichols *et al.*, 1971). A range of infaunal polychaetes and amphipods were also present, but perhaps the most notable characteristic of this habitat is the absence of any epifaunal species.

Ecological Significance of the Tunnel Valleys and their Associated Fauna

The information presented here represents the first targeted ecological study of the tunnel valleys in the Humber REC study area and indeed in the southern North Sea. Although the sampling was limited it has been possible to investigate the biological communities which inhabit these features and in doing so has advanced our understanding of their significance. Despite their differences both the Silver Pit and the Sole Pit support a diverse and abundant benthic community which will no doubt play a significant role in the wider ecosystem, if only in through the provision of valuable food resources.

The Silver Pit supports an extensive and persistent *Sabellaria spinulosa* reef complex which includes patches of *Mytilus edulis* reef in varying stages of a cyclical succession, and carpet reef which is associated with dense brittle star beds. An area of *S. spinulosa* reef to the south of the Silver Pit has been included as a conservation feature in the Inner Dowsing, Race Bank and North Ridge possible Candidate Special Area of Conservation and cSAC which is currently being assessed for inclusion into the Natura 2000 network (JNCC, 2010). The areas of reef identified in the focused study of Silver Pit fall out of the proposed pSAC boundary but it is possible that this may be incorporated into the area protected on the basis of the evidence presented here.

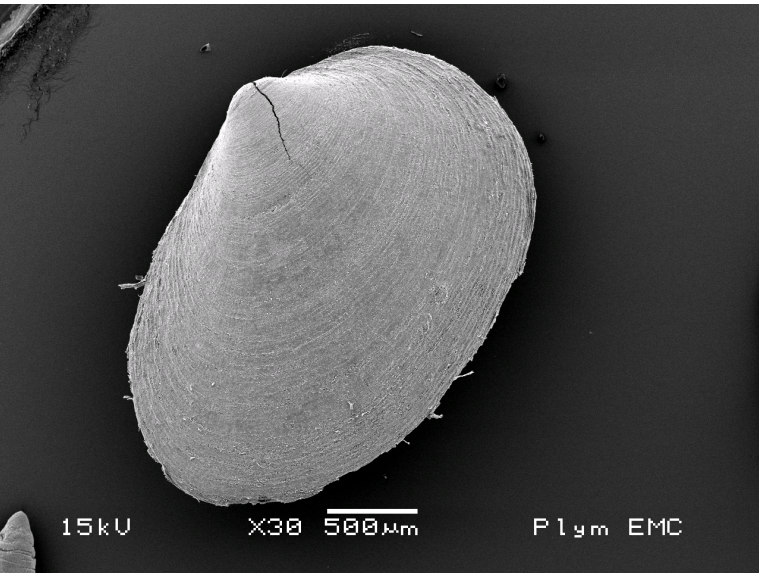


Figure 8.1.8: Scanning Electron Microscope image of *Coracuta obliquata* sampled from the floor of the Sole Pit © Electron Microscopy Centre at the University of Plymouth.

There was no evidence of *S. spinulosa* reef in association with the Sole Pit which suggests that the tunnel valley features of the southern North Sea differ in their ecological significance and role. In order to assess the wider significance of the tunnel valley features, the biological composition of all samples taken from within tunnel valley features were compared with the biological composition recorded across the wider area (Figure 8.1.1). An ANOSIM test found no significant difference between the

Humber REC (259)		Silver Pit (33)		Sole Pit (12)	
Species	n	Species	n	Species	n
<i>Bathyporeia elegans</i>	1.59	<i>Ophiactis balli</i>	0.47	<i>Coracuta obliquata</i>	3.33
<i>Nymphon brevirostre</i>	1.52	<i>Socarnes erythrophthalmus</i>	0.13	<i>Malmgreniella andreapolis</i>	1.33
<i>Alvania semistriata</i>	0.34	<i>Vitreolina philippi</i>	0.13	<i>Hyala vitrea</i>	0.67
<i>Fabulina fabula</i>	0.27			<i>Retusa umbilicata</i>	0.50
<i>Monocorophium acherusicum</i>	0.25			<i>Echiurus echiurus</i>	0.17
<i>Pomatoceros triqueter</i>	0.21			<i>Myriochele danielsseni</i>	0.17
<i>Aonides oxycephala</i>	0.19			<i>Ebalia nux</i>	0.17
<i>Polydora cornuta</i>	0.18			<i>Palio dubia</i>	0.17
<i>Alcyonidium mytili</i>	0.18			<i>Devonia perrieri</i>	0.17
<i>Glycera oxycephala</i>	0.17			<i>Saxicavella jeffreysi</i>	0.17
<i>Urothoe poseidonis</i>	0.17				
<i>Branchiostoma lanceolatum</i>	0.16				
<i>Pisone remota</i>	0.15				
<i>Ischyrocerus anguipes</i>	0.15				
<i>Nicolea venustula</i>	0.13				
<i>Perioculodes longimanus</i>	0.13				
<i>Microporella ciliata</i>	0.11				
<i>Prionospio banyulensis</i>	0.10				
<i>Pseudopotamilla reniformis</i>	0.10				
<i>Elminius modestus</i>	0.10				
<i>Clausinella fasciata</i>	0.10				

Table 8.1.8: Summary of species found to be unique to the Silver Pit (n = 10), the Sole Pit (n=5) and the wider study region in the Outer Humber (n = 110). Only species with an average abundance greater than 0.1 per grab are shown. The total number of unique taxa is given in brackets.

faunal communities within the valleys and those found in the wider environs (R = 0.034, 19.1% Sig). However, this is likely to be influenced in part by the wide variety of habitats and faunal communities found across the Humber REC study area. Despite this, some species were only found in the tunnel-valleys (Table 8.1.8) the most notable being the small bivalve mollusc, *Coracuta obliquata* (Figure 8.1.8) which has only been recorded once in UK waters over the last 100 years (Holmes, *et al.* 2006). This bivalve appears to have very specific environmental requirements, having been recorded in five of the six samples taken from the floor of the Sole Pit. Holmes *et al.* (2006) observed *C. obliquata* in sediments ranging from sand to sandy gravel which corresponds well with our observations in the Sole Pit where this mollusc was observed in gravelly sand.

Coracuta obliquata belongs to the same family of molluscs as *Mysella bidentata* (Montacutidae) which was also present in the floor of the Sole Pit. Many other species of Montacutid molluscs, including *M. bidentata*, are known to have commensal relationships with other invertebrates (Josefson, 1998; Morton and Scott 1969; Tebble, 1966) and it is possible therefore that that the same is true of *C. obliquata*. No such associations have yet been reported for this species and in fact very little is known about *C obliquata* at all, making the floor of the Sole Pit a very valuable study site for this species.

The tunnel valleys clearly represent an important biological resource in the Humber REC study area and since their physical character makes them unsuitable for most anthropogenic activities it is likely that they will continue to do so for many years to come.

8 Features of Stakeholder Interest — 2

8.2 Features of Conservation Interest

In 1992 Europe adopted the EC Habitats Directive (Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora) through which it meets its obligations as a signatory of the Bern Convention on the Conservation of European Wildlife and Natural Habitats. The main aim of the EC Habitats Directive is to promote the maintenance of biodiversity by taking measures to maintain and restore natural habitats and wild species at a favourable conservation status, introducing robust protection for habitats and species of European importance.

Annex II of the EC Habitats Directive lists a number of terrestrial and marine species which are of conservation interest at a European level. These are generally species which are close to extinction and no such species were identified during the course of our surveys of the East Coast REC study area. Annex I of the habitats directive lists habitats which are subject to special requirements for conservation under EU law. A representative proportion of the Annex I habitats are to be protected through a network of Special Areas of Conservation (SACs) which together with Special Protection Areas (SPAs), designated under the Birds Directive, make up the Natura 200 Network. The Natura network will be further supplemented by a new type of marine protected area named Marine Conservation Zones (MCZs) which will be designated under the Marine and Coastal Access Act, 2009.

Eight of the 189 habitats listed in Annex I of the Habitats Directive are marine and seven of these occur in UK waters, namely;

- Sandbanks which are slightly covered by sea water at all times
- Estuaries
- Mudflats and sandflats not covered by seawater at low tide
- Coastal lagoons
- Large shallow inlets and bays
- Reefs
- Submarine structures made by leaking gas



Figure 8.2.2.1: Seabed images showing potential Annex I reef habitats in the Humber REC area A) *Sabellaria spinulosa* reef on the western flanks of the Silver Pit B) Mixed *Sabellaria spinulosa* and *Mytilus edulis* aggregations C) *Sabellaria spinulosa* carpet on the floor of the Silver Pit overlaid with a dense brittle star bed.

Within the Humber REC study area there are a number of habitats which have been identified that could fall into either the Sandbanks or Reefs categories and hence are likely to be of some conservation interest. Definition of these features is a somewhat complex issue driven by a need to define them in law coupled with a general lack of understanding in regard to the ecological functioning of these habitats. The European commission published a guidance document which was subsequently updated (European Commission, 2007a, b). The most accessible definitions of the Annex I habitats are those provided by the Joint Nature Conservation Committee; (material sourced from the JNCC website, accessed 17/10/2010).

Sandbanks

Annex I sandbanks slightly covered by seawater all the time occur where areas of sand are predominantly surrounded by deeper water and where the top of the sandbank is in less than 20 metres water depth. However, the sides of these sandbanks, particularly in offshore waters, can extend into waters deeper than 20m. Some shallow sandbanks are vegetated with eel grass beds or maerl and animals that live on sandbanks include worms, crabs, starfish, sand eels and flatfish such as plaice and sole. The presence of sand eels in particular also makes sandbanks a

rich feeding ground for other wildlife such as seabirds, seals and porpoises.

Reefs

Annex I reefs occur where rocky areas or concretions made by marine animals arise from the surrounding seafloor. There are three main types of Annex I reef: Bedrock reef, Stony reef and Biogenic reef.

Bedrock and stony reefs are both types of rocky reef. These occur where the bedrock or stable boulders and cobbles arise from the surrounding seabed creating a habitat that is colonised by many different marine animals and plants. Rocky reefs can be very variable in terms of both their structure and the communities that they support. They provide a home to many species such as corals, sponges and sea squirts as well as giving shelter to fish and crustaceans such as lobsters and crabs.

Biogenic reefs are those that are created by the animals themselves. In the UK these include coral reefs, made by cold-water corals such as *Lophelia pertusa* and *Madrepora oculata*. Biogenic reefs can also be made by reef-building worms such as the honeycomb worm *Sabellaria alveolata*, the ross worm *Sabellaria spinulosa* and the serpulid worm *Serpula vermicularis*.

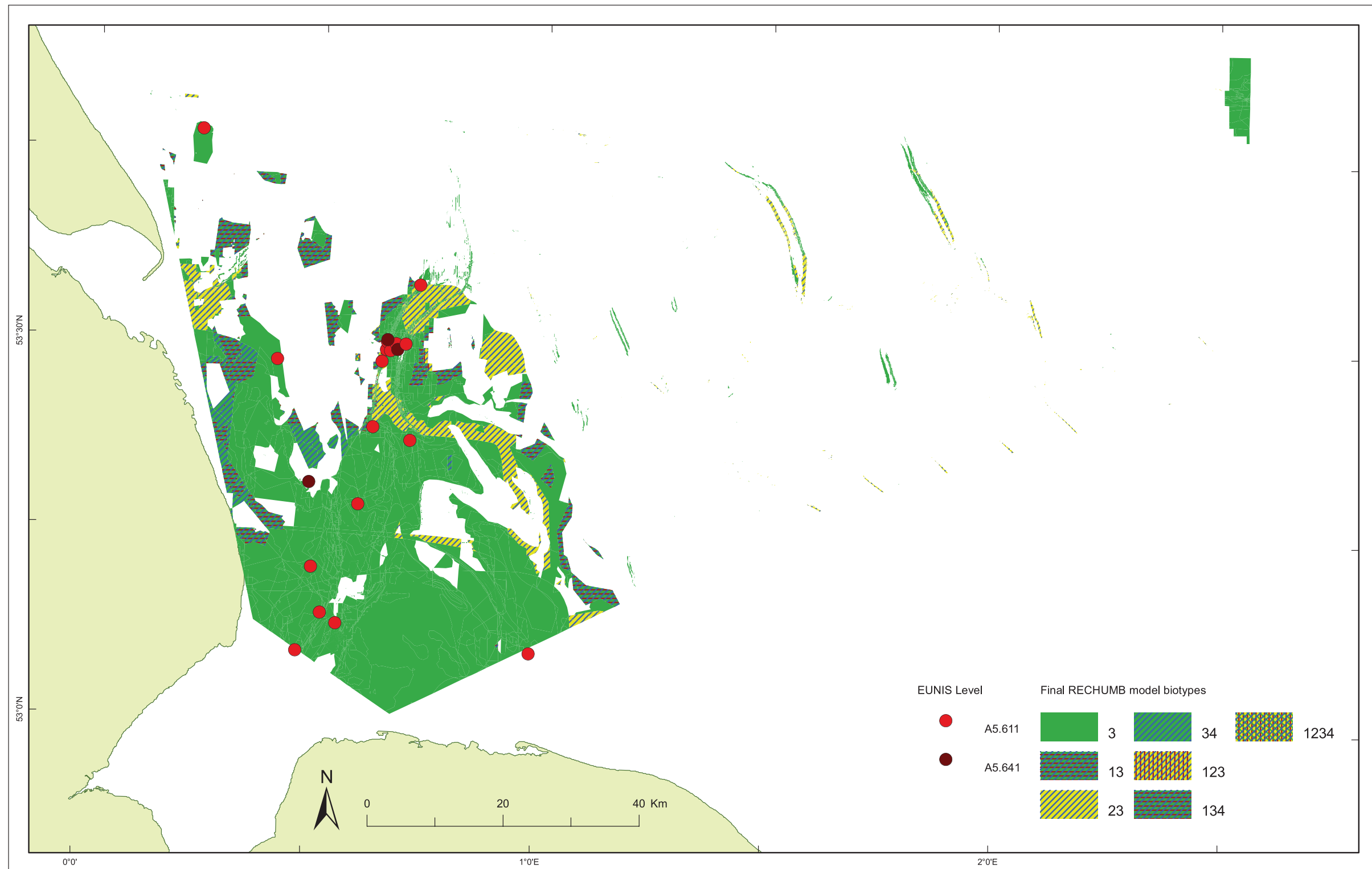


Figure 8.2.2.2: Predicted distribution and actual observations of *Sabellaria spinulosa* reef in the Humber REC study area. The 'Final RECHUMB model biotypes' are predictions for the occurrence of *Sabellaria spinulosa* reef only (Functional Biological Community (FBC) #3 in green) and where two or more of the FBCs (1–Barnacles, ascidians and tubiculous polychaetes, 2–Infaunal polychaetes with burrowing bivalves and amphipods and 4–Sparse fauna) may be present (for example, 13 shows where the predicted likelihood of the presence of FBC 1 is equal to the predicted likelihood of FBC 3 occurring). Actual observations of *Sabellaria spinulosa* (A5.611–*Sabellaria spinulosa* reef and A5.641–*Sabellaria spinulosa* and *Mytilus edulis*) from grab samples are indicated by point data.

Mussels such as the edible mussel *Mytilus edulis* and the horse mussel *Modiolus modiolus* can also create biogenic reef structures. In UK offshore waters the main types of biogenic reef that JNCC are looking to identify additional SACs for are cold-water coral reefs, *Sabellaria spinulosa* reefs and *Modiolus modiolus* reefs.

8.2.1 Sandbanks

There are multiple sand banks within the Humber REC area, from the northern terminations of the Norfolk Banks in the southeast, to the sinuous banks e.g. Race Bank and Dudgeon Shoals, in the west (Figure 8.1.1). The Norfolk Banks and the banks in the central Humber REC study area e.g. Outer Dowsing are composed of fine to medium, very-well sorted sand. The banks in the west are also predominately composed of fine to medium sand, but contain a larger percentage of gravelly sediment at the seabed, particularly around the bank margins. All of the classified sand banks within the Humber REC area, with the exception of two unnamed banks in the far northeast, have crests which at least in part are in waters shallower than 20 m.

Sand eels were recorded in 12 of the 30 2 m beam trawl sample taken across this area with an average of 5 individuals per trawl (Chapter 7.3). Although these are not particularly high abundances the presence of a significant sand eel population in this area cannot be ruled out. Since the majority of these sandbanks lie in water depths of less than 20m this area may be worthy of targeted surveys for comparison with the Annex I sand bank criteria.

8.2.2 Reefs

There are no significant areas of bedrock or stony ground which could be considered as geogenic reef within the Humber REC study area. However, there are a number of habitats which fall under the Annex I category of biogenic reef. The main reef building species identified during this study are the Ross worm *Sabellaria spinulosa* and the blue mussel *Mytilus edulis* which are both listed as specific examples of biogenic reef in Annex I of the habitats directive. Brittle star beds were also identified in the study area and whilst they are not considered to constitute a biogenic reef in themselves they have been identified as sub-features of reef habitats (Hughes, 1998) and so have been included here for completeness.

Web Resources:

Annex I reef — <http://www.jncc.gov.uk/page-1448>

Annex I Sandbanks — <http://www.jncc.gov.uk/page-1452>

8 Features of Stakeholder Interest — 3

8.3 Rare and Alien Species

The identification and monitoring of rare and alien species is an important component of conservation management as part of an overarching goal to preserve national biodiversity.

Rare or scarce species may be at risk of extinction and specific strategies are often required to ensure their persistence. The Joint Nature Conservation Committee (JNCC) developed criteria for the assessment of the rarity of marine benthic species (Sanderson, 1996). Nationally rare species are those which have been recorded in eight or fewer of the 1 546 10 km² squares of the Ordinance Survey national grid and nationally scarce species are those occurring in 9 to 55 squares. A small number of benthic and epibenthic species (including fish) are also listed in the OSPAR List of Threatened and/or Declining Species and Habitats (OSPAR, 2008).

The term ‘alien’ is given to non-native species which have established self-maintaining populations in the UK. Many marine organisms are transported from their native range to ‘new’ areas through the transport and discharge of ballast water, as fouling organisms on ships hulls or through aquaculture. Only a few, however, become invasive with the potential to impact on native species and communities, carry disease, transform ecosystems and cause environmental and economic harm. Where non-native species have not established self-maintaining populations or their origin is not clear they are classified as cryptogenic. This classification is particularly useful as it prevents introduced species from being described as new or rare species. Environmental changes, such as rising sea temperatures in response to climate change, have the potential to impact on the success of new recruits.

A number of rare, scarce and alien species were identified in both the grab and trawl samples taken across the Humber REC area and these are summarised in Table 8.3.1.

8.3.1 Nationally Rare and Scarce Species

Nationally Rare Species

There were two species classified as nationally rare found in the Humber REC area, the colonial hydroid *Obelia bidentata* (Figure

Species	Phylum	Description	Status	Grab samples			Trawl samples		
				No of Records	Abundance	Samples	No of Records	Abundance	Samples
<i>Obelia bidentata</i>	Cnidaria	Erect colonial hydroid	Nationally rare	2	Present	55, 63	0	0	0
<i>Ophelia bicornis</i>	Annelida	Polychaete worm	Nationally rare	1	1	79	0	0	0
<i>Apherusa ovalipes</i>	Crustacea	Amphipod	Nationally scarce	1	1	95	0	0	0
<i>Harpinia laevis</i>	Crustacea	Amphipod	Nationally scarce	1	1	81	0	0	0
<i>Arctica islandica</i>	Mollusca	Black clam	OSPAR Listed	1	1	80	0	0	0
<i>Raja clavata</i>	Chordata	Thornback ray	OSPAR Listed	0	0	0	2	2	T35, T67
<i>Crepidula fornicata</i>	Mollusca	American slipper limpet	Alien in UK	11	32	31, 39, 52, 53, 57, 58, 59, 76, 89, 109, 133	7	127	T30, T39, T52, T57, T59, T82, T86
<i>Elminius modestus</i>	Crustacea	Acorn barnacle	Alien in UK	2	11	58, 133	0	0	0
<i>Monocorophium sextonae</i>	Crustacea	Amphipod	Alien in UK	1	2	118	0	0	0
<i>Mya arenaria</i>	Mollusca	Sand gaper	Alien in UK	7	17	2, 17, 39, 69, 75, 128, 136	0	0	0
<i>Crassikorophium bonnellii</i>	Crustacea	Amphipod	Cryptogenic	6	13	11, 13, 14, 30, 95, 97	0	0	0
<i>Monocorophium acherusicum</i>	Crustacea	Amphipod	Cryptogenic	2	27	52, 54	0	0	0
<i>Photis pollex</i>	Crustacea	Amphipod	Cryptogenic	1	1	62	0	0	0

Table 8.3.1: Summary of rare, alien or threatened species within the Humber REC study area. Abundance is the total number of individuals found across the survey area (Sanderson, 1996; OSPAR, 2008).

8.3.1) and the polychaete worm *Ophelia bicornis*. *Obelia bidentata*, which was found in five samples, has been recorded on non living-hard substrates, both man-made and natural, and also on sandy bottoms. It has been previously found from north Norfolk out to nearly 100 m offshore (Cornelius, 1995) and so is known to occur in the vicinity of this survey. The polychaete *Ophelia bicornis* is thought to flourish in well-drained and well-sorted sands with a negligible solid organic content. Most of the studies looking at the distribution of this species are concentrated in the littoral zone, and have postulated that the distribution of *O bicornis* may be restricted by depth (Harris, 1991). However, *O. bicornis* was recorded at station 79 at a depth of approximately 80 m indicating depth is unlikely to be a limiting environmental factor.

Nationally Scarce Species

Two of the amphipod species recorded from the survey, *Apherusa ovalipes* and *Harpinia laevis*, are recorded as nationally scarce. *Apherusa ovalipes* has a fairly restricted distribution with known records from the Atlantic coast of Europe, the English Channel and the North Sea. *Harpinia laevis* is found in a depth range of 20–200 m and there are occasional records from the North East Atlantic (Lincoln, 1979). In the Humber REC survey only a single individual of each species was found in the grab samples and none were found in the trawls.

Threatened Species

The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) adopted a priority set of species ‘under

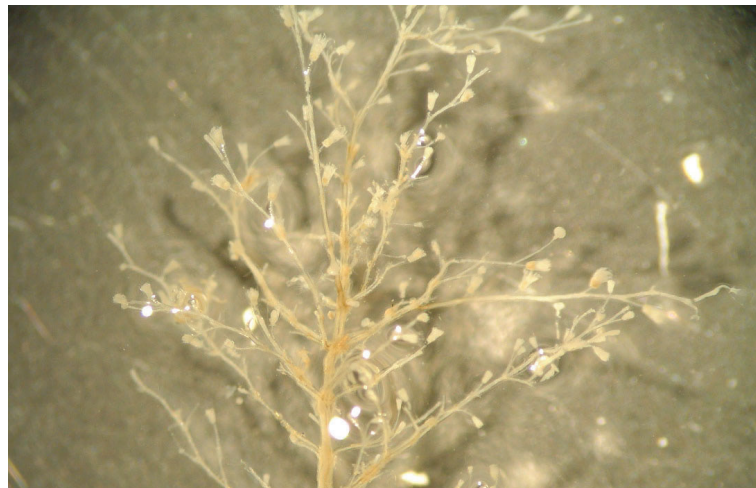


Figure 8.3.1: *Obelia bidentata* © seasurvey.co.uk

threat or in decline' in 2004. This list contains over 40 UK species of invertebrates, fish, reptiles, mammals and birds. Species from this list that were identified during the Humber REC were *Arctica islandica*, a slow growing bivalve, which was found in both grabs and trawls, and from trawls only the thornback ray *Raja clavata* (Figure 8.3.2).

Although not classified as rare or threatened, *Coracuta obliquata*, a bivalve belonging to the family Montacutidae, has only been recorded once in UK waters over the last 100 years (Holmes, *et al.* 2006). Very little is known about this bivalve species and so new records in the Sole Pit are likely to be of considerable scientific interest.

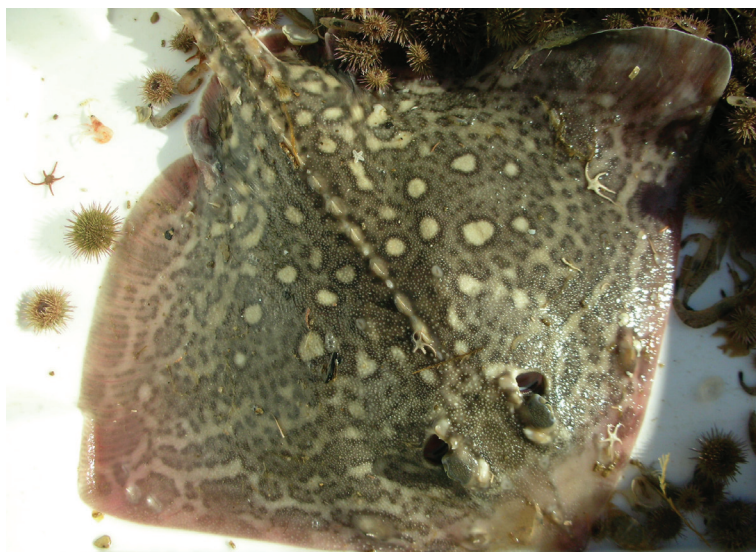


Figure 8.3.2: *Raja clavata* © seasurvey.co.uk

8.3.2 Non-Native Species

Four established alien species were identified during sea bed sampling in the Humber REC study area, the most abundant of these being the American slipper limpet, *Crepidula fornicata* (Figure 8.3.3). The bivalve *Mya arenaria*, the acorn barnacle *Elminius modestus* and the amphipod *Monocorophium sextonae* were also observed but these species were not particularly widespread or abundant.



Figure 8.3.3: *Crepidula fornicata* © seasurvey.co.uk

The invasive American slipper limpet, *Crepidula fornicata*, is a well known alien on British shores, because its introduction has had a detrimental impact on oyster fisheries (Davidson, 1976; Key & Davidson, 1981). The first record of this species in European waters was in Liverpool Bay in 1872 although these populations have since died out (Eno *et al.* 1997). There was also an introduction of *C. fornicata* to the Essex coastline between 1887 and 1890 in association with American oysters *Crassostrea virginica* imported from North America (Eno *et al.* 1997). Other now extinct populations may also have been introduced with the hard clam or quahog *Mercenaria mercenaria* (McMillan, 1938). Since then the American slipper limpet has been accidentally introduced along with other bivalve imports in many other locations and the species is now common throughout Europe.

Crepidula fornicata, was found in 11 of the grab samples and 7 of the trawl samples taken in the Humber REC study area. This species was present in fairly low numbers with a total of

159 individuals recorded across all samples. The slipper limpet is therefore not expected to have the impact on native species observed in other areas such as off the South Coast where it has had a detrimental impact on oyster populations. It is also likely to be at the limit of its temperature tolerance. *Crepidula fornicata* is very sensitive to cold temperatures and massive population crashes have been reported following cold winters (Thieltges *et al.* 2004). It is therefore unlikely that the *C. fornicata* populations identified here will be persistent unless sea temperatures increase.

The long-necked clam *Mya arenaria* is thought to have been introduced to the UK around 1245 by the Vikings as food or bait, or in the bilge water of their boats. This species is considered to be commercially important, although is not currently exploited in the UK (Eno *et al.* 1997; Eno, 1998).

The acorn barnacle *Elminius modestus* native to Australia was first found in Chichester Harbour, Hampshire in 1945. The species is thought to have arrived there in the early 1940s transported from Australia or New Zealand on ships' hulls or possibly as larvae in ships ballast water (Eno *et al.* 1997). In northern areas, such as the British Isles, *Elminius modestus* competes with *Semibalanus balanoides* (Crisp, 1958).

The amphipod *Monocorophium sextonae* was recorded as a new species in Plymouth in the 1930s (Crawford, 1937). The species is native to New Zealand and it has been suggested that increased numbers reduce the numbers of the native species *Corophium bonnellii* (Spooner, 1951).

8 Features of Stakeholder Interest — 4

8.4 Wrecks

The wreck identified during the Humber REC, BA 1000, is likely to be that of the HMS Cape Spartel, a steel fishing trawler requisitioned by the Admiralty in 1939, and is of particular archaeological interest.

The importance of the naval reservists during WWII should not be underestimated.

During the Second World War almost half a million naval reservists enlisted, demonstrating their courage and flexibility by undertaking tasks such as bomb disposal, aviation, coastal escort, mine clearing, landing craft and manning submarines. 15 000 RNPS personnel were killed during this war, and 2385 RNPS seamen who 'have no known grave but the sea'.

The Royal Naval Patrol Service developed from the pre-war Royal Naval Reserve Trawler Section, and had at its peak during WWII 1637 craft of various kinds. Of this total, approximately 260 trawlers were lost in action carrying out minesweeping and convoy escort duties.

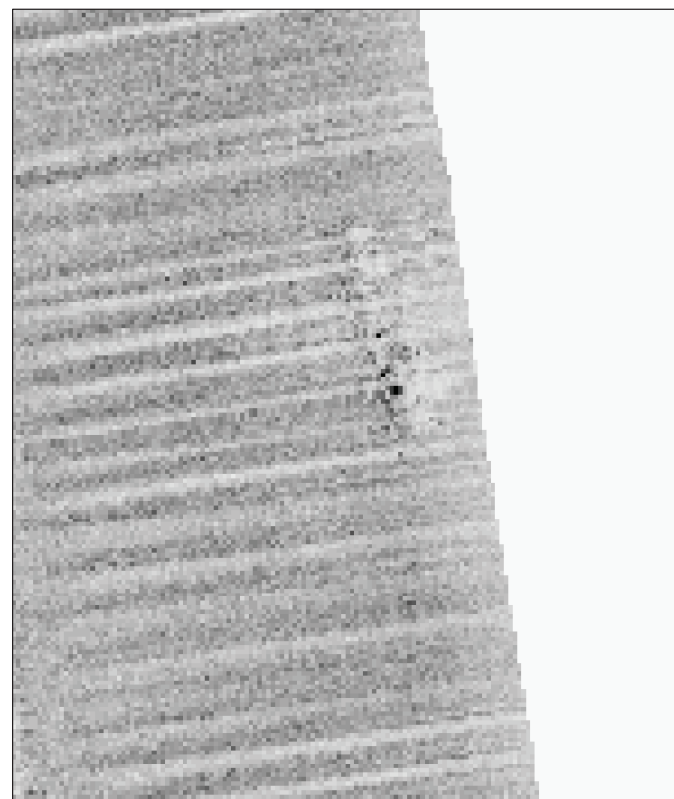
On February 2nd 1942, two of these trawlers were lost in the Humber area. Both of the trawlers were constructed by Cochrane and Sons, and requisitioned by the navy as mine sweepers, and both were lost to air raid by German aircraft, a raid that involved at least 20 planes). One, the Cloughton Wyke was bombed in the Humber Estuary, the other, the HMS Cape Spartel, went down within the study area. Four lives were lost in the sinking of the Cloughton Wyke (ibid), but no mention is given of the fate of the crew of the Cape Spartel (Young 2004, 211). Uboat.net however records that her captain, T/Lt. John Richard Grundy RNR, was given the captaincy of HMS BYMS in July of that year, suggesting that at least he had survived the incident.

The remains of a wreck determined to probably be the Cape Spartel are noted on the NMR, the UKHO/SeaZone dataset, and

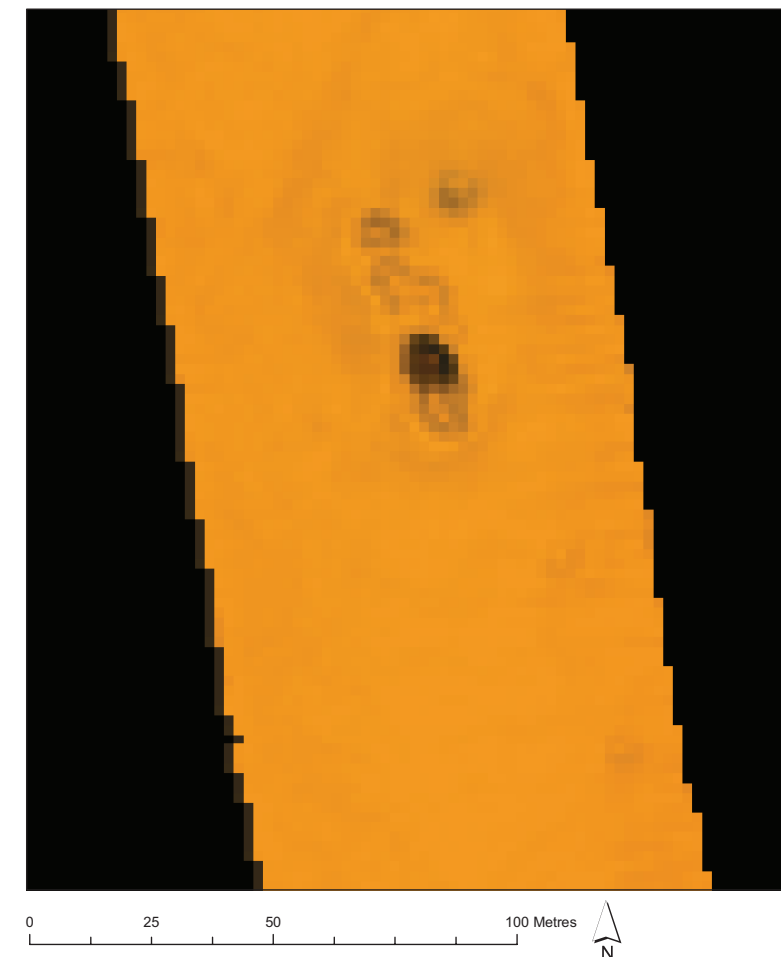
was covered by the sidescan sonar and multibeam bathymetry surveys.

The HMS Cape Spartel has been wire-swept. The wreck is described by Young as lying on the seabed at a general depth of 18m and recorded as dispersed, standing around 4m high amidships. Young reports that 'a number of live shells are scattered on the seabed and one or two instruments from her wheelhouse are visible. Her engine and boiler are now exposed and surrounded by broken machinery. The wreckage covers an area of 64 m by 16 m'. She was on minesweeping duty around the Outer Dowsing Shoal when the boat foundered and was lost, though no mention is made of the crew (Young 2004, 211).

As she was in the employ of the Admiralty at the time of the sinking, the wreck is eligible for designation under the PMRA 1986. Furthermore, as no mention is made of the fate of the crew, it is possible she represents a war-grave. In a wider context she is representative of many vessels that were wrecked in this area, carrying out a range of duties and protecting the vital trade routes during WWII.



BA 1000 Sidescan Sonar



BA 1000 Multibeam Bathymetry



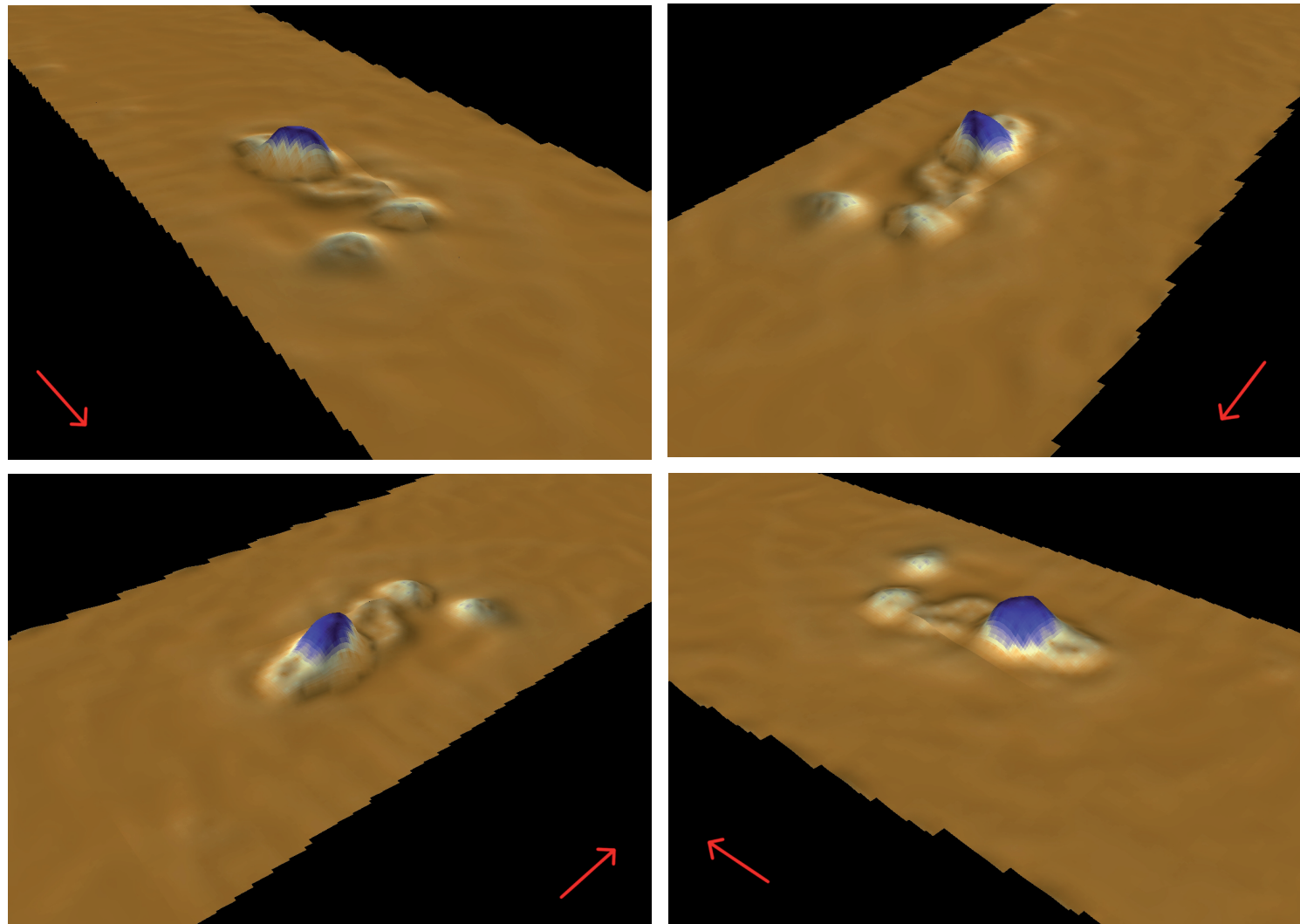
HMS Cloughton Wyke

¹ <http://webarchive.nationalarchives.gov.uk/20101001110155/http://www.royalnavy.mod.uk/operations-and-support/royal-naval-reserve-2/about-rnr/history-of-the-rnr/>

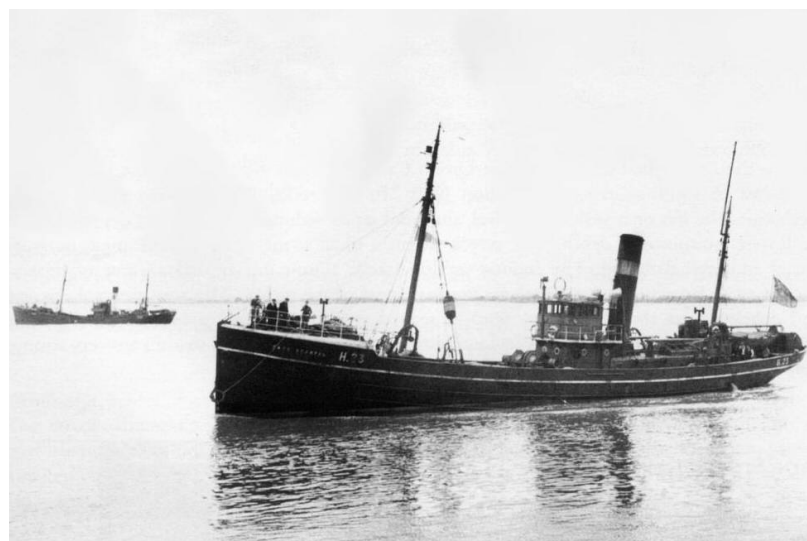
² <http://www.harry-tates.org.uk/>

³ <http://www.wrecksite.eu/wreck.aspx?70406>

⁴ <http://www.uboot.net/allies/commanders/6420.html>



3D Multibeam Bathymetry (vertical axis exaggerated)



HMS Cape Spartel



HMS Cloughton Wyke under attack

8 Features of Stakeholder Interest — 5

8.5 Reid River (Route 18–100N)

The 'Reid River' is one of the most important discoveries of the Humber REC survey and represents a significant resource for understanding the inundated prehistoric landscape of the region. The Humber REC has been instrumental in mapping this location and placing it within the wider landscape of the early Holocene. It has also presented an invaluable opportunity to utilise modern archaeo-environmental analytical techniques to investigate the character of the sediments preserved in the former river channel, which preserve important information regarding the flora and fauna of the river and its surrounding landscape. The study of these palaeochannel deposits demonstrates that sediments and hence possibly any associated archaeological materials survive *in situ* beneath the southern North Sea.

The seismic data for this region records the course and depth of this channel, and indicates that it was part of a series of river channels that flowed north from East Anglia towards the contemporary shoreline, which would have been located around the modern Outer Silver Pit. Some of the features identified as associated with this channel require further study in order to better understand their context and significance. In particular, the larger main channel to the east of VC51 (see Figure 5.6.14) is apparently much deeper and wider than the other areas cored and may well preserve further significant palaeoenvironmental information.

The Reid River is therefore of particular interest to the broader study of Mesolithic Britain, as it contains a well preserved environmental record for an area for which we have very little of such information. The application of multiple analyses and associated scientific dating techniques has produced data illustrating the timing and process of change from the end of the last glaciation (c. 10 000 years before present) to the early Holocene (c. 8 000 BP). There is evidence from these data that the rise in relative sea level may have been more complex in space and time than has been previously been realised. The discovery and associated analyses of sediments from the Reid River thus has implications for archaeology, palaeoenvironmental research and sea level studies. With current concerns over changing sea levels and climate, the study of such sites and the associated implications for the prehistoric populations of the now flooded landscape, are key to understanding the past and planning for the future.

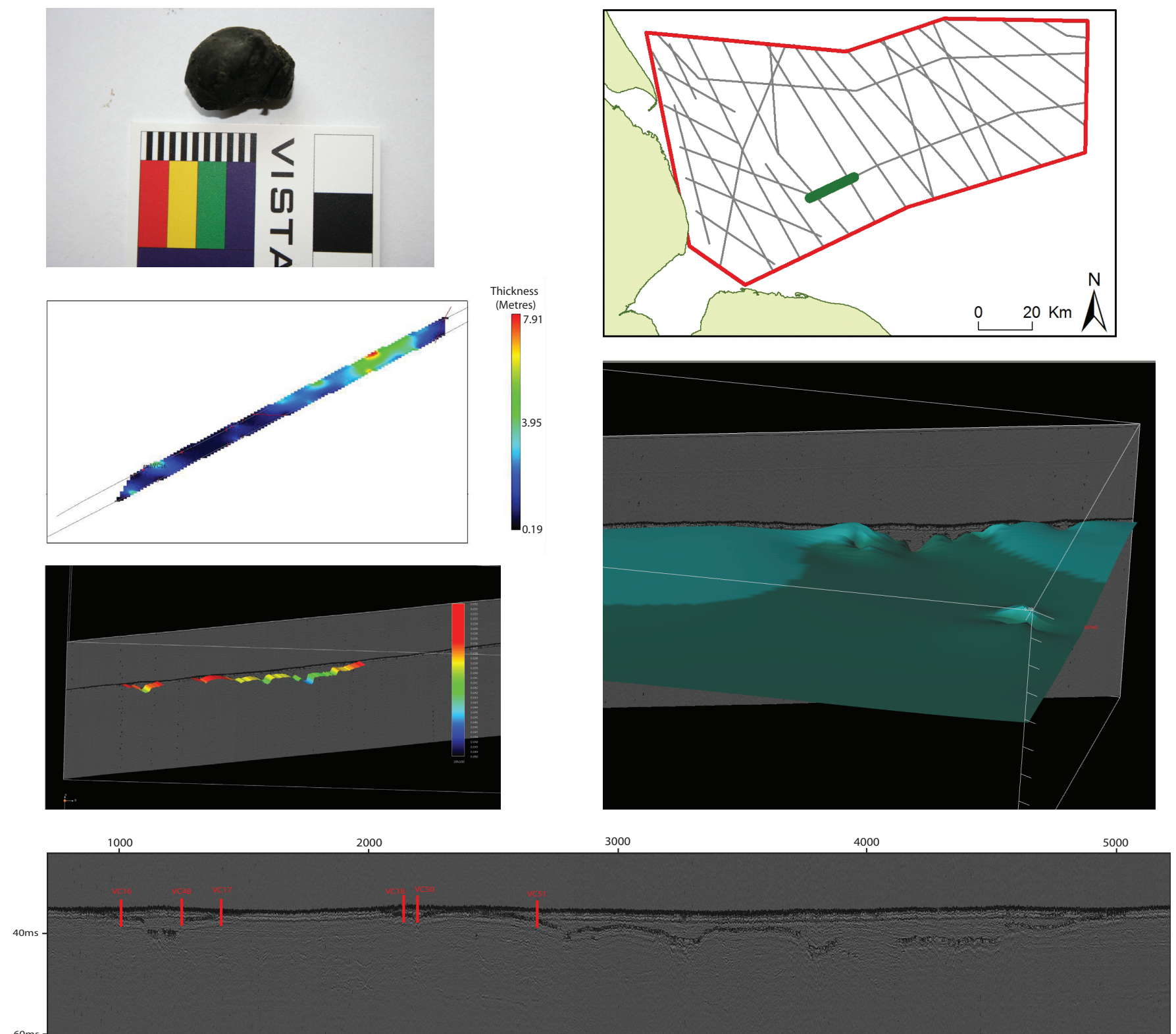


Figure 8.5.1: From top left–clockwise: Hazel nut, dated to the Mesolithic, found in a sample from core VC 50, Location of Reid River (within Route 18-100N), 3D surface of Reid River (dark green delimits the river channel), 2D seismic profile through Reid River showing location of vibrocores, Profile of the base horizon of Reid River, Reid River deposit thickness map.

9 Gap Analysis

Gap Analysis —Survey Design and Data				
Issues	Data Gaps	Implications for REC	Action	Current status
Survey-grid density	MBES, SSS, and seismic line spacing	Large gaps between survey lines prevented complete mapping of survey-scale seabed morphology and sediment distribution which in turn prevents a more precise mapping of habitats and biotopes. It has also prevented the production of isopach maps of sub-seabed geology. Unable to systematically map channel systems and archaeological landscapes	Extrapolate, where possible, in between lines. Use data from other sources	As original
Sample-Station Density	Hamon and Clam Grab, seabed photo	Low sample density necessarily causes lower resolution mapping	Use legacy data e.g. BGS data	As original
Vibrocores	Vibrocores	Limited Vibrocore samples were allocated to Archaeological research aims, thus we were not able to investigate some aspects glacial history as revealed on the geophysical data	Use legacy data e.g. BGS data	As original
Vibrocores	Insufficient core depth penetration of large channel features	The limited depth of material recovered means that the complete record of the palaeochannel systems activity cannot be recovered. Hence, this temporally limits the data in both chronological and palaeoenvironmental terms	None	As original
Multibeam bathymetry survey corridor width coverage	Mutlibeam swath width is narrower than that of the sidescan swath, therefore the areas of coverage are unequal	Not all of the identified sites of archaeological interest in the sidescan sonar data could be matched to a corresponding multibeam swath to provide confirmation of sidescan interpretation	None	As original
Distribution of aircraft wrecks	Difficult to detect with current geophysical methods	Number of aircraft wrecks is seriously underestimated	None	As original
nearshore/inter-tidal waters	Survey corridors do not cover these very shallow water areas	Vessels lost in these areas are not represented in the survey results. This represents a bias in terms of characterising the maritime activity	None	As original
Inshore survey, prevented access	Geophysical Data	The presence of wind-farm development areas, and to a lesser extent, areas with intensive fishing activity prevented access to sizeable areas in the inshore survey area	Modified survey plan	As original
Gap Analysis — Non-Survey Data				
Issues	Data Gaps	Implications for REC	Action	Current status
Gaps in SeaZone data	Predominantly in West	Prevented extrapolation of seabed-morphology and sediment distribution maps being extrapolated from survey-scale to regional scale	Use other data where available	As original
Availability of Windfarm Geophysical Data	All Round 2 windfarms in the area	High resolution MBES data, as well as some geophysical data was collected in advance of contruction of offshore windfarms. Companies are legally obliged to provide this data through COWRIE and Geodata	We tried on multiple occasions to get the data through the designed channels, but were not successful	As original
Fisheries: Breeding and Spawning	Data unavailable	Fisheries review does not include a comprehensive review of the Humber REC study area in terms of its use for fish breeding and spawning	Sought data from Cefas but was under review and could not be supplied within the timeframe of this project	Revised breeding an spawning data currently under review (2010) and should be published by Cefas shortly
Fisheries Effort	MFA data doesn't include <10 m vessel landings and the reliability of the data provided by the MFA is dependent upon the integrity of the documentation provided by the fishermen	Underestimation of <10 m vessel landings for the Humber REC study area	Incorporated expert opinion and used landings data recorded by Sea fishery committees	As original data status not improved

Mammals	Data split over several databases (not centralised)	Underestimation of the use of the area by mammals	All available published sources acquired	Need unified database — single source info
	Lack of coordinated surveys	Reliance on ad-hoc sightings and recorded strandings	All available published sources acquired	Need for coordinated surveys with consistent recording methods
Birds	Disparate databases for nesting sites and seabird observations. Gpas in nesting site data	Underestimation of the use of the area by seabirds	All available published sources acquired	Need unified database for bird nesting sites and observations to aid the assessment of resources used by this group
Sharks	Very minimal shark sightings available. Lack of consistent recording methods	Insufficient data to estimate the use of the area by sharks	Data excluded from the review sue to scarcity of records	Need unified database for shark observations which incorporates sport fishing catches to aid the assessment of resources used by this group
Photic Zone	Low standard data of GIS layers showing depth of 1% irradiance (to calcualte photic zone) and depth of wavebase	The use of UKSeaMap version 2006 has implicated errors in the RECHUMB and EUNIS models. The resolution for the light data changes from 9 km data SeaWifs satellite data to 4 km MODIS satellite data for UKSeaMap 2010. The wave data used in UKSeaMap 2010 has also improved significantly	UKSeaMap version 2010 was requested but was not made available during the model build	Issue unresolved — a new model build using updated UKSeaMap 2010 data would increase confidence in the model
Seabed bathymetrey	SeaZone bathymetry of the area has a high degree of patchiness in some areas	Unable to calculate slope and rugosity correctly in these places	Used coarse scale bathymetry to gap fill these areas but introduced an unlikely pattern of depths in this area	Issue resolved — the best data for the use of the project has been used
Fish stomach data	No fish stomach contents data collected as part of this study and DAPSTOM fish stomach data incomplete and inconsistent	Information difficult to interpret and it has not been possible to provide a comprehensive review of trophic relationships in the Humber REC area	No action taken	Issue unresolved — further research required
Gap Analysis — Interpretation and Data Analysis				
Issues	Data Gaps	Implications for REC	Action	Current status
Quantifying sediment mobility and sediment transport	insufficient data, and diachronous nature of data	We had intended to do more work investigating and quantifying sediment mobiltiy and transport in the area. We set up some scripts to compare time-series data sets (previous Industry data vs. REC data) in this aim.	In the end, there is simply not enough duplication in MBES data to accurately assess this issue, and the various time-stamps on the data added another complication	As original
Pre-19 th Century wrecks	Due to the ephemeral nature of these sites, pre-19 th century wrecks are difficult to detect with current methodologies	It is not possible to characterise the nature of pre-19 th century maritime activity	None	As original
EUNIS/MNCR biotope Classification schemes	The current biotope classification shemes has no way of dealing with rock and thin sediments	Unable to describe areas where rock is overlaid with thin sediments. Forced to shoe-horn these biotopes into a rock or a sediment biotope, neither of which is satisfactory	Utilised the new 'Rock and Thin Sediment' biotope classes proposed under the South Coast and eastern English Channel Synthesis Project	Issue unresolved — will take some time to propose new biotope variants to relevant authorities
	EUNIS states bed shear stress as one of the governing model parameters but only provides a guide to categorising tidal velocities	EUNIS model relied on depth averaged tidal velocities in order to create a model	UKSeaMap2010 bed shear stress (combined tidal and wave) is potentially more accurate and so was used in RECHUMB habitat suitability model	Issue unresolved — requies bed shear stress to be categorised by EUNIS

10 Conclusions

The Humber Regional Environmental Characterisation (REC) provides a robust scientific environmental reference document defining the regional marine environment and character of the seabed. The results of this extensive study, covering an area of over 11 000 km² will be of value to a range of stakeholders including government, marine industries, planners and environmentalists. Data from the Humber REC can be used to improve decision making and contribute to the protection of the marine environment.

The Humber REC has built on the mapping and modelling techniques developed during the other REC projects (for example the Outer Thames and the South Coast). Based on the regional geophysical and sample dataset acquired for the project, together with legacy data, a series of broadscale maps have been produced that characterise the Humber REC area. Accompanying these maps are a series of reports on the geological, biological and archaeological characters of the area.

Of most benefit to stakeholders are:

- The broadscale environmental maps produced during the project,
- The update on previous interpretations, many of which were based on geographically restricted data and on 2D rather than 3D datasets,
- The interdisciplinary nature of the project that results in an integrated overview of the Humber REC area, and
- The integrated GIS of the data acquired and their interpretations.

Geology

Interpretation of the new data set acquired for the Humber REC project together with BGS legacy data has resulted in a new maps of the sediment distribution, sea bed morphology and bedrock exposed at sea bed as well as revised interpretations of its geological evolution over the past 21 000 years. The availability of the SeaZone bathymetry data with the draped sea bed sediment distribution map allows for a more realistic presentation of the

actual sediment grain size distribution. The SeaZone bathymetry also allows more accurate mapping of the deeps and large scale sand bodies present within the Humber REC area. Interpretation of the complete data set acquired during the project has resulted in an improved understanding of the processes responsible for the formation of deeps and for their lack of sediment infill. During the project the development of the semiautomated mapping of sand wave facing directions, provides for a more accurate and comprehensive mapping of the smaller sand waves and their relationship to the prevailing bottom current directions.

Water depths in the Humber REC area are mainly shallow, up to 40 m in the east, with the exception of the deeps where they are up to 100 m. The deeps form a radiating pattern with an apex in the north. Large-scale sandbanks are common throughout the area; with the linear Norfolk Banks in the southeast and a series of smaller-scale sinuous and linear banks in the south east and central regions.

The morphology and sediment distribution are attributed to a number of episodes; initially the region was glaciated and the till of the Bolders Bank Formation was laid down. At this time the deeps were cut by subglacial streams. After deglaciation the till was eroded to leave a thin coarse-grained relict deposit. As sea level rose the area was transgressed, the relict deposit winnowed and fine-grained sediment was transported into the area from the south. This sediment was reworked into the sand banks and sand waves present today over much of the sea bed. The dominance of gravelly sediment in the nearshore areas is the result of strong currents.

The evidence that some of the deeps are free of sediment, some are partially infilled and some of the sub-glacial channels are still completely sediment filled, suggests that all subglacial channels were originally sediment filled, probably by the mechanism described by Praeg (2003). The various present day morphologies of the deeps and the degree of sediment infill is most likely due to the changing environments the Humber REC area experienced during deglaciation and marine transgression. Another significant factor is the relative location of the deeps in regard to the coast as this changed during the post glacial rise in sea level.

Archaeology

The Humber REC area has a diverse archaeological resource ranging in age from the Palaeolithic to the Second World War. This resource can be divided into three broad categories: prehistoric, maritime and aviation. Whilst no artefacts dating to the prehistoric period have been recovered, the area has been identified as of high potential for the preservation of deposits of archaeo-environmental value.

One of the major results of the REC has been the identification and characterisation of the submerged prehistoric landscapes of this region. The approach has combined previous archaeological research with marine geophysical interpretation and associated sampling and analyses of deposits. The palaeoenvironmental analyses and dating programme has illustrated the potential that palaeochannels dating to the early Holocene have to inform our archaeological knowledge of these inaccessible 'hidden landscapes'. The proxy evidence from the vibrocoreing programme has provided new insights into the character of the prehistoric environments of the pre-inundation landscape. This in turn demonstrates that *in situ* sediments with the potential to preserve valuable archaeological material are present in the study area.

The Maritime resource within the Humber REC was successfully characterised with respect to the late 19th century through to the Second World War (WW2) and remains dating to these periods are relatively widely distributed. However, for earlier periods the lack of sufficient data prevented appropriate characterisation. This is most likely due to the nature of the geophysical methods and equipment currently employed as well as the ephemeral nature of the targets. As a result of these various factors it is not possible to provide a definitive statement as to nature and distribution of this resource.

The Humber REC area was a focus of aviation activity, primarily due to the Humber's maritime infrastructure being a key target during WW2. The vast majority of the aircraft wrecks within the region most likely to date to this period. Given the relatively small size and fragility of aircraft wrecks it is perhaps unsurprising that any of these were not identified during the survey. However, it is possible that some of the unclassified geophysical anomalies identified during the survey represent aircraft wrecks. Given this

it is probable that the number of these sites of aircraft wrecks has been underestimated.

Human Uses — Fishing

Commercial fishing by large vessels in the Humber region has historically targeted pelagic whitefish stocks, flatfish and the Norway lobster, *Nephrops*. However, a shift towards potting for crab, lobster and whelk has been observed in recent years. In contrast the inshore fishing fleet principally target shellfish. Wild and cultivated stocks of molluscs and crustaceans, particularly cockles, whelks, mussels and shrimp, are important in the area. Occasionally the inshore fleet also land large quantities of small open ocean species such as herring and sprat when there is a high market demand.

Biological Characterisation

Benthic Invertebrate Communities

Analysis of the benthic macrofauna from grab samples taken in the Humber REC study area revealed 15 discrete assemblages. The majority of these were concentrated to the west of the study area where the physical environment is more heterogeneous. The most frequently recorded assemblage was dominated by infaunal polychaetes and burrowing amphipods including *Bathyporeia elegans*. This community was strongly associated with the sandy substratum which covers much of the eastern half of the study area. The coarser mixed sediments found in the western half of the study area were characterised by a diverse mix of infaunal and epifaunal species including dense aggregations of tubicolous worms, barnacles and ascidians. Biogenic reef complexes formed by *Sabellaria spinulosa*, *Mytilus edulis* and *Ophiothrix fragilis* were also present in this area.

Analysis of the epibenthic trawl samples taken across the Humber REC study area revealed six discrete epifaunal assemblages. As was observed in the benthic macrofauna there was a strong east-west divide with more assemblages found in the more heterogeneous environmental conditions to the west.

Examination of the underwater video footage and digital stills images taken across the Humber REC study area revealed four distinct seabed habitat types; sand, sandy mixed sediments, coarse mixed sediments and exposed boulder clay. Nearly half

of the area was classified as pure sand with a further 20% in the sandy mixed sediment category, highlighting the predominance of sand in this region, especially to the east. Approximately 30% of the area was classified as coarse mixed sediments and exposed boulder clay was observed at just four stations (73, 74, 90 and 111).

The distribution of marine animals is influenced to some extent by the environmental conditions although there is also a large element of chance. This is brought about by the fact that the vast majority of marine benthic species have a planktonic phase in their development. Thus, the recruitment of species is often highly patchy, in time and in space, leading to considerable variability in their distribution. Taking this variation into account biological assemblages identified from the grab and trawl samples were further amalgamated using expert judgement, giving rise to four functional biological communities;

1. Barnacles, ascidians and tubicolous polychaetes
2. Infaunal polychaetes with burrowing bivalves and amphipods
3. *Sabellaria spinulosa* reef
4. Sparse fauna

Marine Mammals

The Humber REC study area is an important region for several marine mammal species providing important habitat, feeding and breeding grounds. The harbour porpoise is the most abundant cetacean within the study area and this region is suggested to represent a significant seasonal nursery area for this species. The area of Donna Nook, at the mouth of the Humber estuary, is home to one of the three major gray seal colonies in the UK and provides a significant breeding and feeding area. Donna Nook also hosts a major population of the harbour seal with many known haul out sites in and around this area.

Seabirds

The Humber region and adjacent coastline contain many internationally important breeding and feeding sites for numerous seabird species, many of which are considered to be threatened or declining in numbers. The heterogeneous geology of the coastline provides important nesting areas for a variety of species and is the

only UK site, outside Scotland and Wales, to support a breeding gannet colony. The region is also important to species that are not native to the UK as it falls within some internationally important migratory routes including the East Atlantic Flyway.

Integrated Assessment of Biotopes and Habitats

The benthic assemblages and functional biological communities were found to be strongly correlated with the environmental conditions across the study area, most notably with sediment composition. Other factors that correlated well with the distribution of fauna in the Humber REC study area included seabed rugosity (calculated using Benthic Terrain Modeller within ArcGIS), shear bed stress and the stratification of the water column.

The predicted distribution of biotopes across the Humber REC study area was mapped in two ways, the first using the EUNIS habitat classification scheme, and the second using habitat suitability modelling. The two modelled maps were then combined to give a biotope map equivalent to Eunis level 5. EUNIS level 4 habitats were modelled across the area by combining the modelled distribution of substrate type, the biological zone (infralittoral, circalittoral and deep circalittoral) and the energy level derived from spring tide current velocities. Using these three environmental parameters the study area was subdivided into ten EUNIS level 4 habitats including habitats assigned to the 'rock and thin sediment' class proposed by James *et al.* 2011. Each of the biological sampling stations was then assigned a EUNIS level 4 classifications on the basis of the sample data available which matched the model in 92% of cases. In all instances where the modelled EUNIS level 4 habitat did not match the habitat identified during sampling, there was some small scale variability in the composition of the sediment deposits. This indicates that the model gives a very good representation of the Humber REC area at a broad scale but differences should be expected at a more local scale.

The EUNIS classification as it stands is not consistent in the way in which it ascribes biological communities to biotopes at Level 5, and beyond. In some cases very broad descriptions are given such as 'Semi-permanent tube-building amphipods and polychaetes in sublittoral sand' and in other instances by specific combinations of species are used such as '*Abra prismatica*, *Bathyporeia elegans*

and polychaetes in circalittoral fine sand'. In order to classify the Humber REC sampling stations in a consistent and repeatable manner, the EUNIS level 4 classifications were combined with the assigned functional biological community to give broad level biotope descriptions (EUNIS level 5). Where there were sufficient samples, a more detailed biotope description based on species composition was also given (EUNIS level 6). A total of 19 biotopes were assigned at level 5 and 18 at level 6. Many of the functional biological communities were found to exist across several of the EUNIS level 4 habitats and hence it is proposed that the environmental parameters used in the EUNIS scheme would benefit from some revision.

Habitat suitability modelling was employed to develop the RECHUMB model which predicts the distribution of the four functional biological communities across the study area based on the environmental conditions under which they were observed. The model revealed clear regional divisions between the four functional biological communities. Community 2 'infaunal polychaetes with burrowing bivalves and amphipods' was the most widely distributed, covering much of the middle and eastern parts of the study area. Communities 1 'barnacles, ascidians and tubicolous polychaetes' and 3 '*Sabellaria spinulosa* reef' were limited mostly to the inshore areas where the sediments are coarser and therefore able to support epifaunal species. Conversely, community 4 'sparse fauna' was scattered across much of the area showing no real affinity to a specific sediment type. There were a number of overlapping habitats predicted and this is understandable given that these functional biological communities are known to have overlapping environmental niches.

The full coverage map of predicted biotope, at EUNIS Level 5 (Fig 7.2.5) provides a good representation of the biological resources across the Humber REC study area. This will provide data that can be used by a range of stakeholders concerned with management and protection of the marine environment.

Recommendations

1. The project has produced new maps and interpretations of the Humber REC area, but the usefulness of the new data acquired as a source of an improved understanding of the area has not been exhausted. There is an opportunity for further work on

the data, on its' own as well in association with the other REC datasets, to better understand the environment of the Southern North Sea region. Thus further work should be carried out on the new data set.

2. Further sampling and analytical work is required to investigate the submerged prehistoric landscapes of the REC area. In particular, the timing, patterns and processes of changes in relative sea level during the early Holocene require further investigation in terms of the implications for human activity and hence possible locations of archaeological sites.

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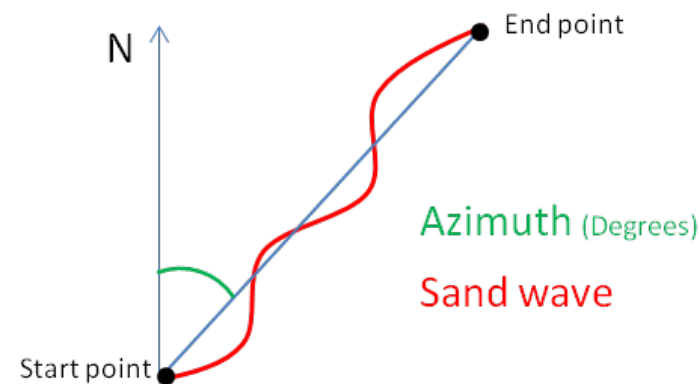
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<http://www.opsi.gov.uk/>

Appendix A — Sand Wave Classification

Azimuth

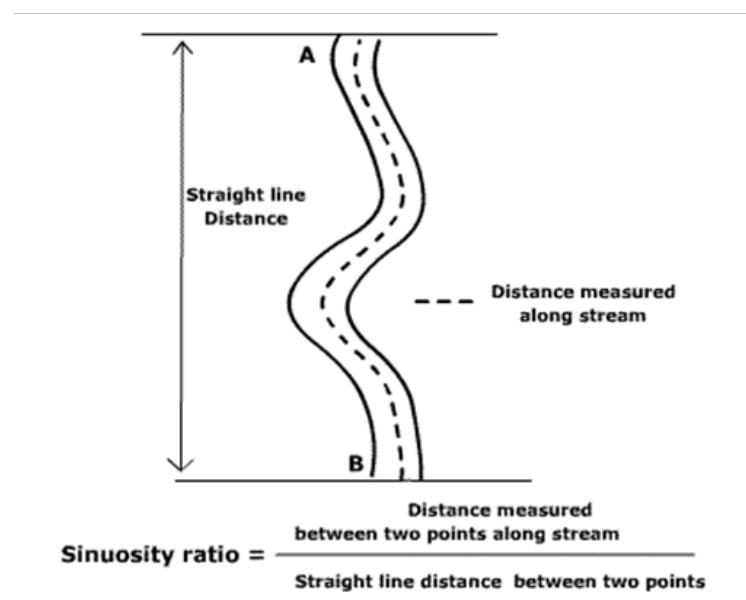
The azimuth value provided is the angle between the line defined by the start and end point of a digitised sand wave and the North:



The start point will always be the one with lower X value (left), therefore the Azimuth will vary just from 0 to <180. If the X value for both points is the same, the starting point will be the one with lower Y value.

Sinuosity

The sinuosity ratio was calculated in the same way as for rivers with meanders:



Where:

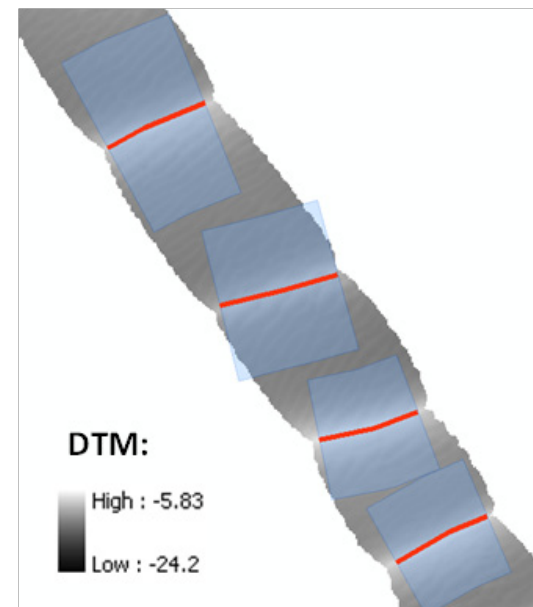
- Sinuosity ratio = Sinuosity field
- Distance measured between two points along stream = sw_Length field
- Straight line between two points = lineLength field

A sand wave with low sinuosity would have a value near to 1, whereas higher values would denote higher sinuosity.

As the crest of the sand waves were digitised on relatively narrow corridors, they are truncated and therefore the sinuosity will be close to 1 in most of the cases.

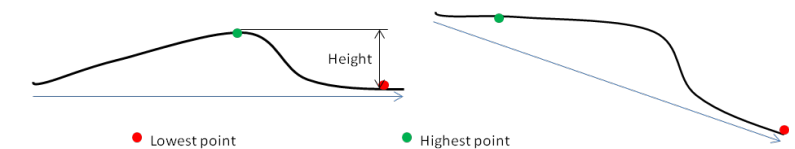
Height

The height value is estimated by creating a buffer surrounding the sand wave, calculating the maximum and minimum DTM values within the buffer, and subtracting one from the other.



The length of the buffer will depend on how far apart are the sand waves from each other, with a maximum buffer of 150 m, and a minimum buffer of 15 m each side of the digitised sand wave, which will avoid overlaps on buffers from different sand waves (as long as they are at least 30 m from each other).

One limitation of this method is when the sand waves are located on a terrain with high slope, as this will change the maximum and minimum DTM values for a sand wave.

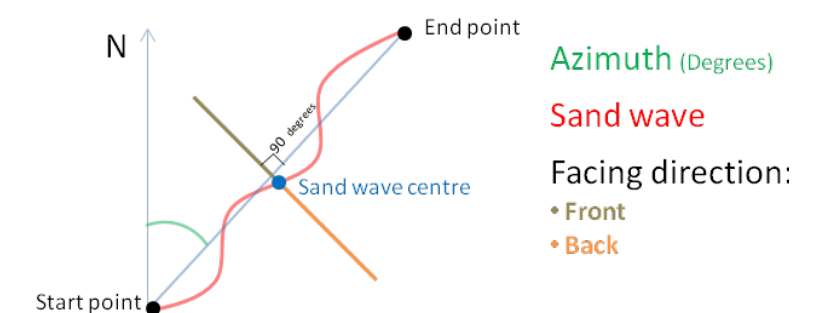


Facing direction

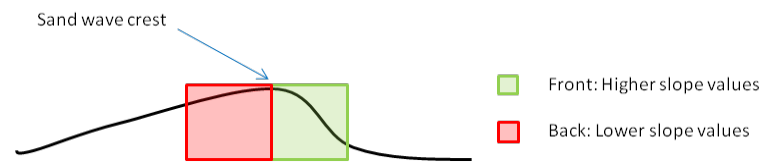
The facing direction (avalanch slope) is given as a column of the sand wave's shapefile, but also as a separate shapefile, from which the column was calculated. The column represents, in degrees, the direction the sand wave is moving towards. For simplicity, the 360° of the facing direction are grouped into 8 main directions (N, NE, E, SE, S, SW, W, and NW) in the field 'Orient'.

The Facing_Direction shapefile shows the facing direction of the sand wave graphically as the perpendicular line to the shortest line that links the start and end point of a sand wave, and it is associated to a particular sand wave through the sw_id field.

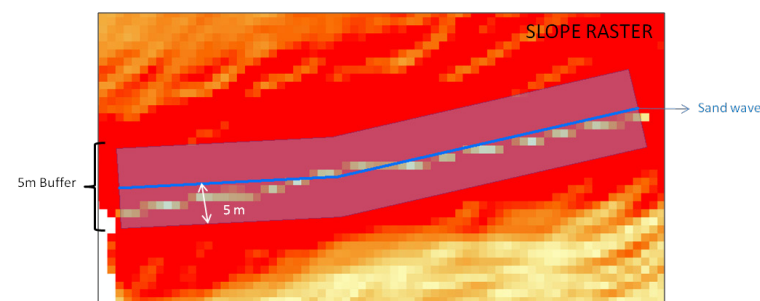
The centre of a facing direction line is coincident with the centre of its sand wave, and its length is proportional to the distance between the start and end point of a sand wave (half of it).



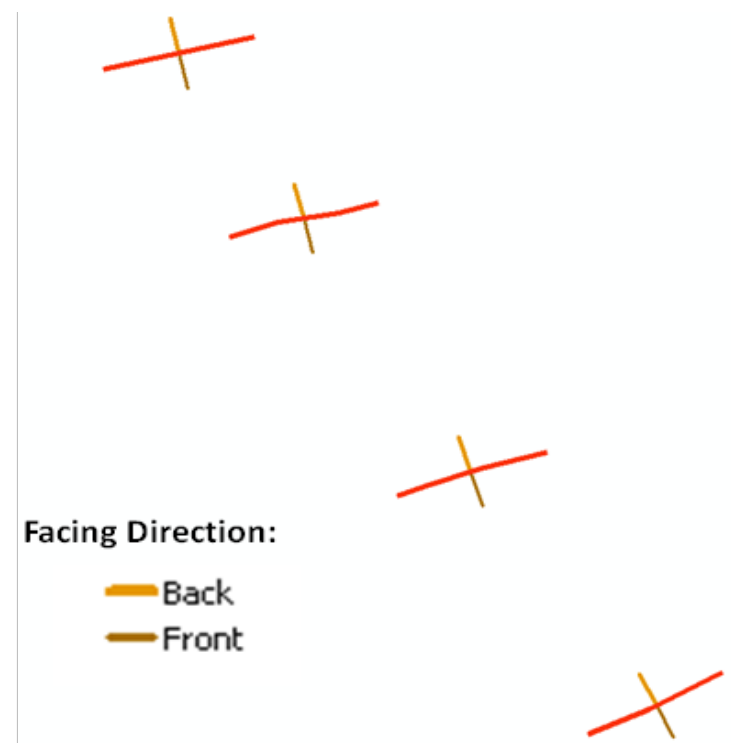
Every facing direction line is actually composed of 2 features, which represent the front and back of the sand wave. They are calculated under the assumption that the steeper side of the sand wave crest will be the front, whereas the other side, with lower slope values, will be the back.



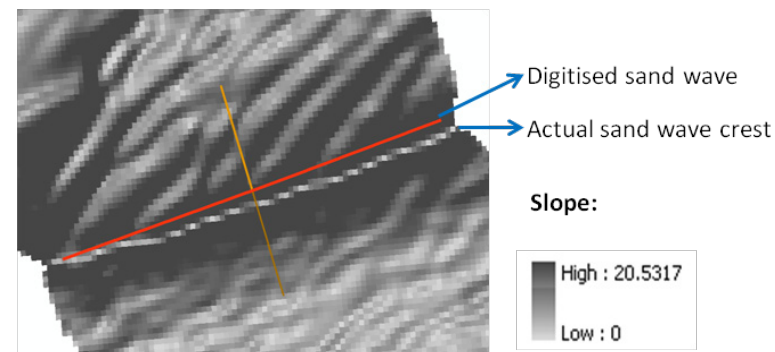
In the GIS this is carried out by creating a 5 m buffer surrounding the delineated sand wave, making an average of the slope values at each side of the sand wave, and assigning front to the higher slope average and back to the lower slope average.



Finally, the front and back values are assigned to the facing direction line shapefile through a spatial join.



Note that, because the sand waves were manually digitised on the top of GeoTiffs, they might not fall exactly on the top of the sand wave crestline, where the slope is near 0 (represented in the picture below with lighter colours). This might lead to some errors in the estimation of the facing direction.



Appendix B — Vibrocore Core Logs

Core	Depth (m)	Nig	Strf	Elas	Sicc	Lsup	Components	Comments		
VC1	0.0–0.10	2	0	0	3	0	Ga2Gg(min)2	Well sorted sand with small subrounded platey stones	10yr 5/6	yellowish brown
	0.10–0.20	2	0	0	3	0	Gg(maj)3Ag1 Ga+	large subangular stones held in a minimal sandy matrix	10yr 4/2	dark greyish brown
	0.20–1	2	0	0	3	0	As2 Ag1 Gg(min)1 ptm+	Silty clay matrix with inclusions of small well rounded mineral particles, fine shell fragments present	10yr 4/3	brown
	1.0–1.89	2	0	0	3	0	Ag2 As2 ptm+sh+	Silty clay with some well humified organic material and shell fragments	2.5yr 3/6	dark red
VC2	0.0–0.34	2	0	0	3	0	Gg(min)2 Gg(maj)2 Ptm+	very coarse sand with large well rounded stones, mostly unsorted	10yr 4/6	dark yellow brown
	0.34–0.44	2	0	0	3	0	Gg(min)3 Ga1 Ptm+	coarse sand with small subangular stones	10yr 4/6	dark yellow brown
	0.44–140	2	0	0	3	0	As3 Ag1 Gg(min)+	Dense grey brown clay (boulder clay)	2.5yr 3/6	dark red
VC9	0.00–0.28	2	0	0	3	0	Ag2 As1Gg(min)1 Ptm	clayey silty matrix of pebbles and shell fragments	5yr 4/1	dark grey
	0.28–0.75	2	0	0	3	0	As3 Gg(min)1	dense clay with small stone inclusions, stones are sharp and angular	5yr 4/3	reddish brown
VC12	0.00–0.16	2	0	0	3	0	Ptm2 Ag1 Ga1 Gg(min)+	Shell dominated sandy silt matrix with some larger mineral particles.	7.5yr 4/4 brown	
	0.16–0.30	2	0	0	3	0	Ptm1 Gg(min)1 Ag1 Ga1	Sandy silt matrix with some mineral particles inclusion and small percentage (10%) shell fragementts	7.5yr 4/4 brown	
	0.30–0.65	2	0	0	3	0	As2 Ag1 Ptm1	Silty clay with small fragments of shell	7.5yr 3/3	
VC15a	0–1.00	2	0	0	3	0	As3 Ag1 Gmin+	Boulder Clay (shells and sands at top)	2.5yr 3/6	dark red
VC16	0–0.15	2	0	0	3	0	Gmin2 Gmaj2 Ptm++	Coarse shelly sands		
	0.15–0.50	3	0	0	3	4	Ag4 Dg+	Grey brown silts, rare humified organics		
	0.50–0.60	3	0	0	3	0	Sh2 Ag1 Gmin1	Brown well humified silty peat with fine sands		
	0.60–0.64	2	0	0	3	0	As3 Gmin1 Gmin++	Becomes grey/brown slightly organic clay with sand and some coarse small gravels (Big pebbles-poorly mixed)		
	0.64–1.00	2	0	0	3	0	As3 Gmin1	Grades into blue grey clay with coarse sands		
	0.90–2.00	3	0	0	3	0	As4 Ptm+	Grey brown dense clay with calcareous fragments and chalky pebbles (1.61–1.64-Wood Sample)		
VC 17	0–0.10							Sands with gravels	10yr 5/4	yellowish brown
	0.10–0.35	2	0	0	3	0	As3 Ag1 DI+	Grey silty clay with occasional humified woody fragments	gley 2 3/5b	very dark bluish grey
	0.35–0.37	2	0	0	3	4	Gmin3 Ag1	Sand Band (with pebbles)	10yr 5/4	yellowish brown
	0.37–0.50	2	0	0	3	0	Ag2 Gmin2 Ptm+ DI+	Dark grey silt with coarse gravels and shell fragments, also humified wood and large flint	gley1 3/n	very dark grey
	0.50–0.80	2	0	0	3	0	As3 Ag1 Gmin+	Pinky brown slightly silty clay with occasional chalky pebbles (0.60–0.62-Sand Band)	5yr 4/4	yellowish red
	0.80–1.00	2	0	0	3	4	Gmin4 Ag+	Fine slightly silty buff sand	5y 6/4	pale olive
	1.00–2.15	2	0	0	3	0	As3 Ag1	Boulder Clay (possible problem with recovery)	2.5yr 3/6	dark red
VC18	0–0.15							Coarse sands shells and gravels		

Core	Depth (m)	Nig	Strf	Elas	Sicc	Lsup	Components	Comments		
	0.15–1.00	2	0	0	2	4	Ag4 Gmin+ DI+	Grey silt with some coarse sands and occasional ?Woody fragments		
	1.00–1.10	2	1	0	3	0	Ag3As1 Sh+ Dh+	Grey brown slightly organic clay silt with thin organic partings, slightly more organic to base		
	1.10–1.43	2	0	0	2	0	Ag2As1 Gmin1 Gmaj+ Sh+	Coarse grey brown sandy silt with rare flints and humified organic material		
	1.43–3.00	2	0	0	2	0	As3Ag1 Sh+	Stiff grey brown clay with occasional chalk gravel and ?Charcoal fragments?		
VC19a	0–0.35	2	0	0	3	0	Gmin2 Gmaj2	Sands and gravels	10yr 5/4	yellowish brown
	0.35–1.00	2	0	0	3	0	As3 Ag1	Boulder clay	2.5yr 3/6	dark red
	1.00–2.00	2	0	0	3	0	As3 Ag1	Boulder clay	2.5yr 3/6	dark red
	2.00–4.00	2	0	0	3	0	As3 Ag1	Boulder clay	2.5yr 3/6	dark red
VC27	0.0–0.15	2	0	0	3	0	Gs2 Gg(min)2 Gg(maj) +Ptm+	coarse sand with platey subrounded mineral inclusions, occasional larger stone and shell pieces	10yr 5/4	dark yellowish brown
	0.15–0.40	2	0	0	3	0	Gs3 Gg(min)1 Ptm+	gradual transition into a finer grained sand with small sized well rounded stones	10yr 5/4	dark yellowish brown
	0.40–0.64	2	0	0	3	0	As1 Ag2 Gg(miin)1 Ga+	clayey silt with small rounded stones throughout, slight maganese staining	10yr 3/1	very dark grey
	0.64–0.99	2	0	0	3	0	Ga3 Ag1 + Gg(min)1 Ga+	fine sand small amount of binding silt. Managense staining with a 1% incusion of small stones	2.5y–4/3	olive brown
	0.99–152	2	0	0	3	0	As2 Ag2 Gg(min)+	boulder clay	10yr 4/2	dark greyish brown
VC25	0.0–0.87	2	0	0	3	0	Gg(min)3 ptm1	Coarse sandy matrix comprising of large amounts of small mineral stones and broken shell	10yr 6/4	light yellowish brown
	0.87–1.00	2	0	0	3	0	Gg(min)2 ptm2	Coarse sandy matrix comprising shell and small rounded and platey stones	10yr 6/4	light yellowish brown
	1.00–2.00	2	0	0	3	0	Gg(min)3 ptm1	Well sorted sand comprising of small shell fragments and stones	10yr 6/4	light yellowish brown
	2.00–3.83	2	0	0	3	0	Gg(min)2 Gs2 Ptm+	Well sorted medium fine sand with individual, small sized whole shells	10yr 6/4	light yellowish brown
	383–388	2	0	0	3	0	As2Ag2Ga+	Clay-silt	10yr 3/1	very dark grey
	388–4.21	2	0	0	3	0	Gg(min)2 Gs2 Ptm+	Well sorted medium fine sand with fine shell pieces throughout	10yr 6/4	light yellowish brown
VC26	0–1.00	2	0	0	3	0	Gmin4	Medium coarse sands	10yr 5/4	yellowish brown
	1.00–2.00	2	0	0	3	0	As3 Ag1	Sands onto boulder clay (exact depth of transition unknown as not opened yet)	2.5yr 3/6	dark red
VC 29	0–0.50	2	0	0	3	0	Gmin2 Gmaj2 Ptm++	Shell rich coarse sands and gravels	7.5yr 5/4	brown
	0.50–0.75	2	0	0	3	0	Gmin3 Ag1	Grey medium coarse shelly sands with occasional flints	7.5yr 5/2	brown
	0.75–1.36	3	0	0	3	4	Ag3 As1 Dg+	Grey clayey silt, black mottled humified organic fragments	10yr 3/1	very dark brown
	1.36–1.44	4	0	0	3	4	Sh2 Ag1 Dg1	Black brown well humified silty peat with wood fragments	10yr 2/1	black
	1.44–1.60	4	0	0	3	0	Ag3 Sh1 As+	Grey brown organic silt with humified organic detritus	gley1 3/10y	grey
	1.60–1.81	2	0	0	3	0	Gmin4 Ag+	Grey medium coarse sands slightly silty with chalky gravels to base	5yr 4/1	dark grey

Core	Depth (m)	Nig	Strf	Elas	Sicc	Lsup	Components	Comments		
VC29a	Duplicate of 29									
	0–0.40	2	0	0	3	0	Gmin4	Medium coarse sands	10yr 5.6	yellowish brown
	0.40–0.70	2	0	0	3	0	Gmin3 Ag1 Ptm+	Grey slightly silty sand with shell fragments (at 0.66 m-very thin organic band 3–4 mm)	10yr 5/2	greyish brown
	0.70–1.00	3	0	0	3	2	As2 Ag2 Dg+	Grey silty clay with occasional humified organics	10yr 3/1	very dark grey
	1.00–1.85	3	0	0	3	0	Ag3 As1	Grey clayey silts	gley1 3/n	very dark grey
	1.85–2.00	4	0	0	3	2	Sh2 Ag2	Silty peat	7.5yr 3/1	very dark grey
	2.00–2.10	3	0	0	3	2	Ag3 As1	Grey clayey silts	10yr 3/2	very dark greenish brown
	2.10–2.15	3	0	0	3	4	As3 Dg1	Grey brown organic lense-clay	7.5yr 3/1	very dark grey
	2.15–2.45	2	0	0	3	4	Gmaj2 Gmin2 As+	Grey coarse gravelly sand, slightly clayey with pebbles	10yr 4/1	dark grey
	2.45–3.48	2	0	0	3	2	As4 Ag+	Grey clay with chalk fragments, slightly silty	10yr 4/1	dark grey
VC 29b	0.19–0.38	0	0	0	3	1	Gmin3 Gmaj+ ptm1	buff coarse shelly sand		
	0.38–0.53	2	0	0	1	1	Gmin2 Gmaj1ptm1	dark brown coarse shelly sand		
	0.53–0.72	3	0	0	1	1	Gmin2 Gmaj+ Ag+ ptm1	grey shelly sand, occasional silt		
	0.72–1.24	3	1	2	2	4	Ag3 Dg1 As+	smooth grey silt clay, occ organics, weakly laminated		
	1.24–1.31	5	0	0	2	1	Dg1 Ag2 As1 Ga+	Black well humified peat, woody at top		
	1.31–1.76	4	0	0	2	1	Dg1 Sh3 Ag +	Black brown organic silt clay		
	1.76–2.03	3	0	0	2	3	Ag1Ga1 Gmin1 Gmaj+	Fine silty grey sand, siltier at base		
	2.03–2.96	2	0	0	2	1	Gmin2 Gmaj1 Ag+	Brown red sand with pebbles		
VC34	0–1.05	2	0	0	3	0	Gmin3 Gmaj1	Coarse shell rich gravelly sand (bottom of the sea)	10yr 5/4	yellowish brown
	1.05–3.05	2	0	0	3	2	As3 Ag1	Boulder Clay	2.5yr 3/6	dark red
VC35	0–0.68	2	0	0	3	0	Gmin3 Ptm1	Medium coarse shell rich sands	10yr 5/4	yellowish brown
	0.68–1.00	2	0	0	3	0	Gmin4	Coarse sands, No shells	10yr 5/4	yellowish brown
	1.00–2.00	2	0	0	3	0	Gmin4 Ptm+	Coarse sands with occasional shells	10yr 6/8	brownish yellow
	2.00–3.00							Unopened due to machine error — looks like continuation of the upper unit		
	3.00–3.66	2	0	0	3	0	Gmin4	Coarse sands	10yr 5/4	yellowish brown
	3.66–3.68	2	0	0	3	2		Layer of pebbles	10yr 6/8	brownish yellow
	3.68–4.00	2	0	0	3	4	As4	Grey clay	10yr 4/1	dark grey
VC 39	0–1.00	2	0	0	3	0	Gmin3 Gmaj1	Coarse orange shell rich sands with gravels	10yr 5/6	yellowish brown
	1.00–1.25	2	0	0	3	0	Ag3 Gmin1	Grey silt with very fine sands, black mottled	5yr 4/1	dark grey
	1.25–1.34	2	0	0	3	0	Ag4	Grey black mottled silt	gley2 3/5b	very dark grey
	1.34–2.00	2	0	0	3	0	As3 Ag1	Red brown clay (boulder)	2.5yr 3/6	dark red

Core	Depth (m)	Nig	Strf	Elas	Sicc	Lsup	Components	Comments		
VC 39a	0–1.36	0	0	0	4	0	Gmin2 Gmaj2 ptm++	coarse buff shelly sands		
	1.36–2.29	2	1	0	2	0	Gmin2 As2 Ag+	Laminated pale fine sands, occ brown clay, occ patches grey silt		
	2.29–3.36	2	0	0	2	3	As3 Gmin1	Red brown sandy clay, inclusions of worn pieces of stone, charcoal flecks		
VC40a	0.00–1.00	2	0	0	3	0	Gmin3 Gmaj1	coarse sands	10yr 5/6	yellowish brown
	1.00–1.83	2	0	0	3	0	Gmin2 Gmaj2	Coarse sands and gravels	10yr 6/6	brownish yellow
VC40	0.0–0.20	2	0	0	3	0	Ga4	medium fine sand with no inclusions	10yr 6/8	brownish yellow
	0.20–0.60	2	0	0	3	0	Gg(maj)3 Ga1	sand matrix holding large, rounded and frost shattered stones	10yr 6/8	brownish yellow
	0.60–2.0	2	0	0	3	0	Ga1 Gs1 Gg(min)1 Gg(maj)+	sandy matrix with small and large stone inclusions, these were unsorted	10yr 6/8	brownish yellow
VC46	0–0.19	2	0	0	3	0	Gg(min)1 Gg(maj)2 Ptm1	medium coarse sand with large complete mussel shells with large unsorted stones	10yr 5/6	yellowish brown
	0.19–0.65	2	0	0	3	0	Gs2 Gg(min)1 Ptm1	coarse sand with a variable range of mineral particles. Small calcareous shells present.	10yr 5/6	yellowish brown
VC 47	0–1.10	1	0	0	3	0	Gmin2 Gmaj2	Beige coarse sands, some shells and gravels	10yr 5/6	yellowish brown
	1.10–2.32	1	0	0	3	0	Gmaj2 Gmin1 Ptm1	Sand becoming gravel and shell rich	10yr 5/6	yellowish brown
	2.32–3.84	2	0	0	3	0	Gmin4	Dark beige fine sand with occasional lenses of coarse shelly sands, occasional black partings?	10yr 6/6	brownish yellow
VC 47a	0–2.00	2	0	0	3	0	Gmin2 Gmaj2 ptm+++	Hard shelly coarse sand		
	2.00–3.30	1	2	0	3	4	Gmin3 Ag1	weakly laminated soft buff sand, charcoal in the laminations, wood at 3.17 m		
	3.30–3.31	3	3	0	3	4	Ag3 Ga1	Grey green silt, sharp upper and lower transition		
	3.31–3.81	1	2	0	3	4	Gmin3 Ag1	laminated buff sand with charcoal laminations		
	3.81–3.82	3	3	1	3	4	Ag3 As+	grey green silt clay, occasional charcoal, wood @ 3.83, just below transition		
	3.82–4.07	1	2	0	3	0	Gmin2 Gmaj1	Soft buff sand, weakly laminated, wood @ 3.94, darker at base		
VC 48	0–0.10							Shelly sands	10yr 5/6	yellowish brown
	0.10–1.28	2	1	0	2	4	As4 Gmin DI+ Dh+	Grey silt with some coarse sands and occasional woody fragments and monocots, weakly laminated	gley/ 2.5 10gy	greenish black
	1.28–1.34	4	0	0	2	2	Ag2 Sh1 Dg1 DI+	Grey brown mottled peaty silt with organic detritus inc wood fragments and monocots	10yr 2/1	black
	1.34–1.60	3	0	0	3	0	Gmin2 As1 Ag1 Dg+	Grey brown clayey sand with coarse sand and occasional humified organic remains	10yr 3/1	very dark grey
	1.60–1.88	2	0	0	2	0	As3Ag1	Boulder clay -stiff grey brown clay with occasional chalk gravel	10yr 2/2	very dark brown
VC48a	Duplicate of 48 - sampled for bulks. Extra 1m of boulder clay recovered at base									
VC49a	0.0–0.30	2	0	0	3	0	Gg(min)2 Gg(maj)2	coarse sand with shell and mineral inclusions, these are unsorted and semi rounded.	10yr 6/6	brownish yellow

Core	Depth (m)	Nig	Strf	Elas	Sicc	Lsup	Components	Comments		
	0.30–0.69	2	0	0	3	0	Ag2 Gg(min)2 Gg(maj)+ Dh+	silty matrix with fine mineral sands. Some larger stone inclusions. Some unhumified organic matter	2.5y 2.5/1	black
	0.69–1.00	2	0	0	3	0	Ag3 As1 Gg(min)+	silty matrix with fine quartz mineral particles. A few small inclusions of calcareous shell	2.5y 3/3	dark olive brown
	1.00–1.28	2	0	0	3	0	Ag2 Gg(min)1 As1 Gg(maj)+	clayey silt matrix, a small number of larger stones that are sub-rounded	2.5y 3/3	dark olive brown
	1.28–2.08	2	0	0	3	0	As2 Ag1 Ga1 Gg(min)+	silty, sandy, clay. <0.6mm inclusions, semi rounded and platy. Chalk inclusions at 5%. Maganese staining	7.5yr 4/6	strong brown
VC49	0.0–0.14	2	0	0	3	0	Ga2 Gg(min)1 ptm1	coarse sand with small stones	10 yr 5/6	yellowish brown
	0.14–30	2	0	0	3	0	Sh2 Ag2	organic rich silt, very sharp boundary	10yr 3/1	very dark grey
	0.30–0.36	2	0	0	3	0	sh3 Ag1	rich, well humified organic sediment, with a small amount of silt. Very sharp boundary	10yr 2/1	black
	0.36–0.83	2	0	0	3	0	Ag2 Sh1 As1 Gg(min)+	clayey, silty, organic matrix with 1% small mineral inclusions. Slightly less organic content at the transition to next zone		
VC 50	0–0.20	2	0	0	3	0	Gmin3 Ptm1	Coarse shelly sands	10yr 5/4	yellowish brown
	0.20–0.50	2	0	0	3	2	Ag3 Gmin1 Ptm+	Grey silt with coarse sands, shell fragments	7.5yr 3/1	very dark grey
	0.50–1.75	2	0	0	3	0	Ag2 As2 Sh+	Grey clayey silt, slightly organic	gley1 3/10y	dark grey
	1.75–2.04	2	0	0	3	0	Ag3 Gmin1 Ptm+	Grey blue weakly laminated silts with shells and shelly fragments	gley1 3/n	dark grey
	2.04–2.34	2	0	0	3	2	Ag2 Ptm2	Grey blue weakly laminated silts becoming more shell rich	gley1 3/n	dark grey
	2.34–2.44	2	0	0	3	2	Ag2 Sh2 Dg+	Dark grey brown peaty silt with humified orgaincs	7.5yr 2.5/2	very dark brown
	2.44–3.40	2	0	0	3	2	As2 Gmin2 Gmaj+ Sh+	Grey sandy clay, rare humified organics and flinty pebbles	2.5 3/1	very dark grey
	3.40–3.90	2	0	0	3	0	Gmin2 Gmaj1 Ag1	Grey sandy clay becoming a coarse grey silt with large pebbles and occasional black clasts, angular pebbles	5y 3/1	very dark grey
	3.90–4.40	2	0	0	3	0	As3 Ag1	Boulder clay	2.5yr 3/6	dark red
VC 51	0–0.15	2	0	0	3	0	Gmin3 Ptm1	Shelly sands	10yr 5/6	yellowish brown
	0.15–1.30	2	0	0	3	2	Ag4 Dg+	Grey silt with occasional humified organics becoming coarser below 1m with sands and fine gravels	2.5yr 3/1	very dark grey
	1.30–1.50	2	0	0	3	0	Ag2 Gmin2 Sh+ Dg+	Grey sandy silt with occ humified organics	5yr 3/1	very dark grey
	1.50–2.63	2	0	0	3	0	As3 Ag1	Boulder Clay	2.5yr 3/6	dark red
VC51a	0–0.10 m							Mixed and loose, was possibly shelly sand		
	0.10–0.95	4	0	0	4	1	Dh1 Ag3 As1 ptm++ Gmin++	Black grey organic silt, bands of shelly sand at 0.24–0.27 m and 0.38–0.42 m		
	0.95–1.20	3	0	0	4	1	Ag2 Gmin2	Light grey silt sand		
	1.20–2.36	2	0	0	4	1	Ag2 As2	Light brown silt clay occ charcoal, occ chalk		

Appendix C — Pollen Assessment of Cores

Core	Depth (m)	Stratigraphy	Pollen — Main Species	Concentration	Preservation	Comments
VC29	0.74	Grey clayey silt	<i>Corylus, Quercus, Pinus, Ulmus, Cyperaceae</i>	Excellent (5)	Excellent (5)	
	0.78		<i>Corylus, Quercus, Pinus, Poaceae</i>	Excellent (5)	Excellent (5)	
	0.82		<i>Concentration too low for assessment. Few grains of Corylus, Quercus, Betula, Pinus, Chenopodiaceae</i>	Very low (-1)	Very Poor (-1)	uncountable
	0.86		<i>Corylus, Quercus, Pinus, Poaceae</i>	V.Good (4/5)	Good (4)	
	0.90		<i>1 Cyperaceae grain</i>	Absent-V.Low (0/1)	n/a	uncountable
	0.94		<i>Corylus, Quercus, Pinus, Poaceae</i>	V.Good (4/5)	Good (4)	
	0.98		<i>Corylus, Quercus, Pinus, Ulmus, Poaceae,</i>	V.Good (4/5)	Good (4)	
	1.02		<i>Corylus, Quercus, Pinus, Poaceae,</i>	V.Good (4/5)	Good (4)	
	1.06		<i>Corylus, Poaceae, Pinus, Quercus, Ulmus</i>	V.Good (4/5)	Good (4)	
	1.10		<i>Corylus, Quercus, Pinus, Poaceae</i>	V.Good (4/5)	Good (4)	
	1.14		<i>Corylus, Poaceae, Pinus, Quercus, Ulmus</i>	V.Good (4/5)	Good (4)	
	1.18		<i>Corylus, Poaceae, Pinus, Quercus, Ulmus</i>	V.Good (4/5)	Good (4)	
	1.22		<i>Corylus, Quercus, Pinus, Poaceae</i>	Excellent (5)	V.Good (4/5)	
	1.26		<i>Corylus, Poaceae, Pinus, Quercus, Ulmus</i>	V.Good (4/5)	Good (4)	
	1.30		<i>Corylus, Quercus, Pinus, Poaceae</i>	V.Good (4/5)	Good (4)	
	1.34		<i>Corylus, Quercus, Poaceae, Ulmus</i>	Excellent (5)	Excellent (5)	
	1.36	Black well humified silty peat	<i>Corylus, Quercus</i>	V.Good (4/5)	Good (4)	
	1.40		<i>Corylus, Quercus</i>	V.Good (4/5)	Poor-Medium (2/3)	Corroded, degraded and crumpled grains
	1.44	Organic silt	<i>Corylus, Pinus</i>	Medium (3)	Medium (3)	
	1.48		<i>Corylus, Pinus</i>	Good (4)	Poor (2)	Corroded, degraded and crumpled grains
	1.52		<i>Corylus, Pinus</i>	Good (4)	Poor (2)	Lots of crumpled grains
	1.56		<i>Concentration too low. Some Pinus, Corylus, Pteropsida and unidentifiable grains.</i>	V.Low (1)	Poor (2)	Uncountable Corroded, degraded and crumpled grains
	1.64	Silty sand	<i>Corylus, Poaceae, Quercus, Pinus, Chenopodiaceae</i>	Good (4)	Poor (2)	Corroded, degraded and crumpled grains
VC29b	0.73	Grey silty clay with occasional organics, weakly laminated	<i>Corylus, Quercus, Ulmus, Pinus</i>	Good (4)	Medium (3)	
	0.77		<i>Corylus, Quercus, Pinus, Poaceae, Cyperaceae</i>	Good (4)	Medium (3)	
	0.81		<i>Pinus, Corylus, Quercus, Poaceae, Cyperaceae</i>	Low (2)	Medium (3)	2 slides counted
	0.85		<i>Pinus, Corylus, Quercus, Poaceae, Chenopodiaceae</i>	Medium (3)	Poor (2)	Lots of crumpled grains
	0.89		<i>Corylus, Pinus, Quercus, Poaceae</i>	Good (4)	Medium (3)	
	0.93		<i>Corylus, Pinus, Quercus, Poaceae</i>	Good (4)	Medium (3)	
	0.96		<i>Concentration too low for assessment. 18 grains of Corylus</i>	Very low (-1)	Very Poor (-1)	uncountable
	1.00		<i>Corylus, Quercus, Pinus, Poaceae, Cyperaceae</i>	Good (4)	Medium (3)	
	1.04		<i>Concentration too low for assessment. 11 grains of Corylus</i>	Very low (-1)	Very Poor (-1)	uncountable
	1.08		<i>Corylus, Quercus, Poaceae</i>	Good (4)	Medium (3)	

Core	Depth (m)	Stratigraphy	Pollen — Main Species	Concentration	Preservation	Comments
	1.12	Grey silty clay with occasional organics, weakly laminated	<i>Corylus, Quercus, Pinus, Poaceae</i>	Good (4)	Medium (3)	
	1.16		<i>Corylus, Quercus, Pinus, Poaceae</i>	Medium (3)	Medium (3)	
	1.20		<i>Pollen almost absent apart from 1 grain of Pteropsida</i>	-	-	Large clumps of organic matter — unable to break down uncountable
	1.24	Well humified peat	<i>Corylus, Quercus, Pinus, Poaceae</i>	Good (4)	Good (4)	
	1.28		<i>Quercus, Corylus, Poaceae</i>	Good (4)	Medium (4)	Lots of crumpled grains
	1.32	Black/brown organic silty clay	<i>Few grains of Pteropsida and Corylus</i>	Very low (-1)	Very Poor (-1)	uncountable
	1.36		<i>Few grains of Pinus, Corylus, Pteropsida</i>	Very low (-1)	Very Poor (-1)	uncountable
	1.40		<i>Few grains of Pteropsida and Corylus</i>	Very low (-1)	Very Poor (-1)	uncountable
	1.44		<i>No pollen</i>	Absent (0)	Absent (0)	uncountable
	1.48		<i>Few grains of Pinus, Pteropsida</i>	Very low (-1)	Very Poor (-1)	uncountable
	1.52		<i>2 grains of Corylus</i>	Very low (-1)	Very Poor (-1)	uncountable
	1.56		<i>No pollen</i>	Absent (0)	Absent (0)	uncountable
	1.60		<i>1 grain of Cyperaceae</i>	Very low (-1)	Very Poor (-1)	uncountable
	1.64		<i>No pollen</i>	Absent (0)	Absent (0)	uncountable
	1.68		<i>1 grain of Betula</i>	Very low (-1)	Very Poor (-1)	uncountable
	1.72		<i>No pollen</i>	Absent (0)	Absent (0)	uncountable
	1.76		<i>No pollen</i>	Absent (0)	Absent (0)	uncountable
	1.90	Grey fine silty sand	<i>No pollen</i>	Absent (0)	Absent (0)	uncountable
	1.94		<i>1 Alnus, 1 Quercus, 1 Corylus</i>	Very low (-1)	Very Poor (-1)	uncountable
	1.99		<i>1 Alnus, 1 Corylus</i>	Very low (-1)	Very Poor (-1)	uncountable
	2.02		<i>2 grains of Corylus</i>	Very low (-1)	Very Poor (-1)	uncountable
VC48	0.24	Grey silt	<i>Corylus, Poaceae, Quercus, Pinus, Ulmus</i>	Excellent (5)	Excellent (5)	
	0.28					
	0.32		<i>Corylus, Quercus, Ulmus, Poaceae</i>	Excellent (5)	Excellent (5)	
	0.36					
	0.40		<i>Corylus, Poaceae, Quercus, Pinus, Ulmus</i>	Excellent (5)	Excellent (5)	
	0.44					
	0.48		<i>Corylus, Ulmus, Quercus, Pinus, Poaceae</i>	Excellent (5)	Excellent (5)	
	0.52					
	0.56		<i>Corylus, Poaceae, Quercus, Ulmus, Pinus</i>	Excellent (5)	Excellent (5)	
	0.60					
	0.64					
	0.68		<i>Corylus, Quercus, Poaceae, Pinus</i>	Excellent (5)	Excellent (5)	
	0.76		<i>Corylus, Poaceae, Quercus, Ulmus, Pinus</i>	Excellent (5)	Excellent (5)	
	0.80					
	0.84		<i>Corylus, Quercus, Ulmus, Poaceae, Pinus</i>	Excellent (5)	Excellent (5)	

Core	Depth (m)	Stratigraphy	Pollen — Main Species	Concentration	Preservation	Comments
	0.88	Grey silt				
	0.94		<i>Corylus, Poaceae, Quercus, Pinus, Ulmus</i>	Excellent (5)	Excellent (5)	
	0.98					
	1.02		<i>Corylus, Quercus, Poaceae, Pinus, Ulmus</i>	Excellent (5)	Medium (3)	
	1.06					
	1.14		<i>Corylus, Quercus, Poaceae</i>	Good (4)	Excellent (5)	
	1.18					
	1.22		<i>Corylus, Quercus, Poaceae, Ulmus</i>	Good (4)	Good (4)	
	1.26					
	1.30	Peaty silt	<i>Corylus, Pinus</i>	Low (1)	Poor (1)	
	1.32					
	1.34					
	1.44	Clayey sand				
	1.60					
VC50	0.18	Grey silt with coarse sands	<i>Corylus, Quercus, Pinus, Ulmus, Poaceae</i>	V.Good (4/5)	Good (4)	
	0.22		<i>Corylus, Quercus, Pinus, Poaceae</i>	V.Good (4/5)	Good (4)	
	0.26		<i>Corylus, Quercus, Pinus, Poaceae</i>	V.Good (4/5)	Good (4)	
	0.30		<i>Corylus, Quercus, Pinus, Poaceae</i>	V.Good (4/5)	Good (4)	
	0.34		<i>Corylus, Quercus, Pinus, Poaceae</i>	Low (2)	Good (4)	
	0.38		<i>Corylus, Quercus, Pinus, Poaceae, Ulmus</i>	V.Good (4/5)	Good (4)	
	0.42		<i>Corylus, Quercus, Pinus, Poaceae, Ulmus</i>	V.Good (4/5)	Good (4)	
	0.46		<i>Corylus, Quercus, Pinus, Poaceae, Ulmus</i>	V.Good (4/5)	Good (4)	
	0.50	Grey clayey silt, slightly organic	<i>Corylus, Ulmus</i>	Excellent (5)	Excellent (5)	
	0.54		<i>Corylus, Quercus, Pinus, Ulmus, Poaceae</i>	Excellent (5)	Excellent (5)	
	0.58		<i>Corylus, Quercus, Poaceae, Pinus, Chenopodiaceae</i>	V.Good (4/5)	Good (4)	
	0.62		<i>Corylus, Quercus, Poaceae, Pinus</i>	V.Good (4/5)	Good (4)	
	0.66		<i>Corylus, Quercus, Poaceae, Ulmus</i>	V.Good (4/5)	Good (4)	
	0.70		<i>Corylus, Quercus, Poaceae</i>	V.Good (4/5)	Good (4)	
	0.74		<i>Corylus, Quercus, Poaceae, Pinus</i>	V.Good (4/5)	Good (4)	
	0.78		<i>Corylus, Quercus, Pinus, Poaceae, Ulmus</i>	V.Good (4/5)	Good (4)	
	0.86		<i>Corylus, Quercus, Pinus, Poaceae, Ulmus</i>	Low-Medium (2/3)	Medium (3)	
	0.90		<i>Corylus, Quercus, Poaceae</i>	Good (4)	Good (4)	
	0.94		<i>Corylus, Quercus, Poaceae, Pinus</i>	Good (4)	Good (4)	
	0.98		<i>Corylus, Quercus, Poaceae, Ulmus</i>	Low-Medium (2/3)	Good (4)	
	1.02		<i>Corylus, Quercus, Poaceae, Ulmus</i>	Good (4)	Good (4)	
	1.10		<i>Corylus, Quercus, Poaceae, Pinus</i>	V.Good (4/5)	Good (4)	
	1.14		<i>Corylus, Quercus, Pinus, Poaceae, Ulmus</i>	V.Good (4/5)	Good (4)	

Core	Depth (m)	Stratigraphy	Pollen — Main Species	Concentration	Preservation	Comments
	1.18	Grey clayey silt, slightly organic	<i>Corylus, Quercus, Poaceae, Pinus</i>	V.Good (4/5)	Good (4)	
	1.22		<i>Corylus, Quercus, Pinus, Poaceae, Ulmus</i>	V.Good (4/5)	Good (4)	
	1.26		<i>Corylus, Quercus, Poaceae</i>	V.Good (4/5)	Good (4)	
	1.30		<i>Corylus, Quercus</i>	V.Good (4/5)	Good (4)	
	1.34		<i>Corylus, Quercus, Pinus, Poaceae</i>	V.Good (4/5)	Good (4)	
	1.38		<i>Corylus, Quercus, Pinus, Ulmus, Poaceae</i>	V.Good (4/5)	Good (4)	
	1.42		<i>Corylus, Quercus, Pinus, Ulmus, Poaceae</i>	V.Good (4/5)	Medium (3)	
	1.46		<i>Corylus, Quercus, Poaceae</i>	V.Good (4/5)	Good (4)	
	1.50		<i>Corylus, Quercus</i>	V.Good (4/5)	Good (4)	
	1.54		<i>Corylus, Quercus, Poaceae, Pinus</i>	V.Good (4/5)	Good (4)	
	1.58		<i>Corylus, Quercus</i>	V.Good (4/5)	Good (4)	
	1.62		<i>Corylus, Quercus, Pinus, Ulmus, Poaceae</i>	Excellent (5)	V.Good (4/5)	
	1.66		<i>Corylus, Quercus,</i>	V.Good (4/5)	Medium (3)	
	1.70		<i>Corylus, Quercus, Pinus, Ulmus</i>	V.Good (4/5)	Good (4)	
	1.74	Grey blue weakly laminated silts	<i>Corylus, Quercus, Pinus, Ulmus</i>	Good (4)	Medium (3)	Minerogenic
	1.78		<i>Corylus, Quercus, Poaceae, Ulmus</i>	Good (4)	Good (4)	
	1.82		<i>Corylus, Quercus, Poaceae, Ulmus</i>	Good (4)	Good (4)	
	1.86		<i>Corylus, Quercus, Pinus, Poaceae, Ulmus</i>	V.Good (4/5)	Good (4)	
	1.90		<i>Corylus, Quercus, Pinus, Poaceae, Ulmus</i>	V.Good (4/5)	Good (4)	
	1.98		<i>Corylus, Quercus, Poaceae, Betula, Ulmus</i>	V.Good (4/5)	Good (4)	
	2.02		<i>Corylus, Quercus, Pinus</i>	V.Good (4/5)	Good (4)	
	2.06		<i>Corylus, Quercus, Pinus, Ulmus, Poaceae</i>	V.Good (4/5)	Good (4)	
	2.08		<i>Corylus, Quercus, Poaceae, Betula, Ulmus</i>	V.Good (4/5)	Good (4)	
	2.10		<i>Corylus, Quercus, Pinus, Poaceae, Ulmus</i>	V.Good (4/5)	Good (4)	
	2.18		<i>Corylus, Quercus, Pinus, Poaceae</i>	V.Good (4/5)	Good (4)	
	2.24		<i>Corylus, Quercus, Pinus, Ulmus, Poaceae</i>	V.Good (4/5)	Good (4)	
	2.26		<i>Corylus, Quercus, Poaceae</i>	V.Good (4/5)	Good (4)	
	2.30		<i>Corylus, Quercus, Poaceae, Pinus</i>	V.Good (4/5)	Good (4)	
	2.34	Peaty silt with humified organics	<i>Corylus, Quercus</i>	Good (4)	Medium (3)	
	2.38		<i>Corylus, Quercus, Pinus, Ulmus</i>	Low-Medium (2/3)	Medium-Good (3/4)	
	2.42		<i>Corylus, Quercus</i>	Good (4)	Good (4)	
	2.44	Grey sandy clay	<i>Corylus, Pinus, Cyperaceae</i>	Medium (3)	Poor (2)	
			Concentration too low. 1 grain of <i>Corylus</i> , 1 grain of <i>Hedera helix</i> , 2 grains of <i>Quercus</i>	Very low (-1)	Very Poor (-1)	uncountable
	2.64	Grey sandy clay	No pollen	Absent (0)	Absent (0)	uncountable
	2.80		No pollen	Absent (0)	Absent (0)	uncountable
	2.96		No pollen	Absent (0)	Absent (0)	uncountable

Core	Depth (m)	Stratigraphy	Pollen — Main Species	Concentration	Preservation	Comments
VC51	3.12	Grey sandy clay	No pollen	Absent (0)	Absent (0)	uncountable
	3.28		No pollen	Absent (0)	Absent (0)	uncountable
	0.16	Grey silt	<i>Corylus</i> , Poaceae, <i>Quercus</i> , <i>Ulmus</i>	Excellent (5)	Excellent (5)	
	0.20					
	0.24		<i>Corylus</i> , Poaceae, <i>Pinus</i>	Excellent (5)	Excellent (5)	
	0.28					
	0.32		<i>Corylus</i> , Poaceae, <i>Quercus</i> , <i>Pinus</i>	Excellent (5)	Excellent (5)	
	0.36					
	0.40		<i>Corylus</i> , Poaceae, <i>Quercus</i> , <i>Pinus</i>	Excellent (5)	Excellent (5)	
	0.44					
	0.48		<i>Corylus</i> , Poaceae, <i>Quercus</i> , <i>Pinus</i> , <i>Ulmus</i>	Excellent (5)	Excellent (5)	
	0.52					
	0.56		<i>Corylus</i> , <i>Quercus</i> , Poaceae, <i>Pinus</i>	Excellent (5)	V.Good (4/5)	High Sparganium indet.
	0.60					
	0.64		<i>Corylus</i> , <i>Quercus</i> , Poaceae, <i>Pinus</i>	Excellent (5)	V.Good (4/5)	
	0.68					
	0.72		<i>Corylus</i> , <i>Quercus</i> , Poaceae, <i>Ulmus</i> , <i>Pinus</i>	Excellent (5)	V.Good (4/5)	
	0.76					
	0.80		<i>Corylus</i> , Poaceae, <i>Quercus</i> , <i>Ulmus</i>	Good (4)	Medium-Good (3/4)	
	0.84					
	0.88		<i>Corylus</i> , <i>Pinus</i> , <i>Quercus</i> , Poaceae	Medium-Good (3/4)	Medium (3)	High Sparganium indet.
	0.92					
	1.00		<i>Corylus</i> , Poaceae, <i>Quercus</i> , <i>Pinus</i>	Good (4)	Medium (3)	High Sparganium indet.
	1.04					
	1.08		Low concentration for assessment <i>Quercus</i> (1 grain), <i>Pinus</i> (2 grains) <i>Corylus</i> (1 grain)	Low (1)	Medium (3)	uncountable
	1.12					
	1.16		Low concentration Poaceae (1 grain)	Low (1)	Medium (3)	uncountable
	1.20					
	1.24		No pollen	n/a	n/a	uncountable
VC51a	0.10	Black grey organic silt	<i>Corylus</i> , <i>Quercus</i> , <i>Pinus</i> , Poaceae	Good (4)	Good (4)	
	0.18		<i>Corylus</i> , <i>Quercus</i> , <i>Ulmus</i> , Poaceae	Good (4)	Good (4)	
	0.22		<i>Corylus</i> , <i>Pinus</i> , Poaceae, <i>Quercus</i>	Low (2)	Medium (3)	
	0.30		Low Concentration for assessment <i>Corylus</i> (46 grains), Poaceae (10)	V.low (1)	Medium (3)	uncountable
	0.34		<i>Corylus</i> , <i>Quercus</i> , <i>Pinus</i> , Poaceae	Good (4)	Good (4)	
	0.38		<i>Corylus</i> , <i>Quercus</i> , <i>Pinus</i> , Poaceae	Good (4)	Good (4)	High Sparganium indet.

Core	Depth (m)	Stratigraphy	Pollen — Main Species	Concentration	Preservation	Comments
	0.42	Black grey organic silt	<i>Corylus, Quercus</i>	Medium (3)	Medium (3)	Minerogenic
	0.46		<i>Corylus, Quercus, Pinus</i> , Poaceae	Good (4)	Medium (3)	
	0.50		<i>Corylus</i> , Poaceae, <i>Quercus, Pinus</i>	Good (4)	Good (4)	
	0.54	Black grey organic silt	<i>Corylus</i> , Poaceae, <i>Quercus, Pinus</i>	Good (4)	Low-Medium (2/3)	Corroded and degraded grains
	0.58		<i>Corylus, Quercus</i> , Poaceae Lots of <i>Sparganium</i>	Medium (3)	Low-Medium (2/3)	
	0.62		<i>Corylus, Quercus, Pinus</i> , Poaceae Lots of <i>Sparganium</i>	Good (4)	Medium (3)	
	0.66		<i>Corylus, Quercus, Pinus</i> , Poaceae Lots of <i>Sparganium</i>	Very Good (4/5)	Medium (3)	
	0.70		<i>Corylus, Quercus, Pinus</i> Lots of <i>Sparganium</i>	Very Good (4/5)	Medium (3)	
	0.74		1 grain of <i>Corylus</i>	Very low (-1)	Very Poor (-1)	uncountable
	0.78		2 grains of <i>Betula</i> , 2 grains of <i>Corylus</i> , 1 <i>Cyperaceae</i> and 1 <i>Sparganium</i>	Very low (-1)	Very Poor (-1)	uncountable
	0.82		No pollen	Absent (0)	Absent (0)	uncountable
	0.86		No pollen	Absent (0)	Absent (0)	uncountable

Appendix D — Results of the Beetle Assessments

Core	VC29a				VC 48a			Phytophage plant hosts (nomenclature follows that of Stace 1997)
Depth	1.85–2.10 cm	1.42–1.85 cm	1.00–1.42 cm	1.25–1.50 cm	1.00–1.25 cm	0.45–0.90 cm	0.0–0.45 cm	
COLEOPTERA								
Carabidae								
<i>Pterostichus</i> spp.	1	-	-	-	-	-	-	
<i>Agonum</i> sp.	1	-	-	-	-	-	-	
<i>Dromius longiceps</i> Dej.	-	-	-	1	-	-	-	
Dytiscidae								
<i>Hydroporus</i> spp.	-	1	-	-	-	-	-	
Hydraenidae								
<i>Hydraena</i> spp.	-	2	1	-	-	-	-	
<i>Ochthebius</i> spp.	-	2	-	-	-	-	1	
Hydrophilidae								
<i>Cercyon tristis</i> (Ill.)	1	-	-	-	-	-	-	
<i>Hydrobius fuscipes</i> (L.)	1	-	-	-	1	-	-	
<i>Enochrus</i> spp.	-	-	-	-	1	-	-	
<i>Cymbiodyta marginella</i> (F.)	1	-	-	-	1	-	-	
Orthoperidae								
<i>Orthoperus</i> spp.	-	2	-	-	-	-	-	
Ptiliidae								
Ptilidae Genus & spp. indet.	1	-	-	-	-	-	-	
Staphylinidae								
<i>Lesteva</i> spp.	1	-	-	1	-	-	-	
<i>Stenus</i> spp.	-	-	-	-	-	1	1	
<i>Lathrobium</i> spp.	-	1	-	-	-	-	-	
Aleocharinidae Genus & spp. Indet.	1	-	-	-	-	-	-	
Pselaphidae								
<i>Brachygluta</i> spp.	-	1	-	-	-	-	-	
Eucnemidae								

Core	VC29a				VC 48a			Phytophage plant hosts (nomenclature follows that of Stace 1997)
Depth	1.85–2.10 cm	1.42–1.85 cm	1.00–1.42 cm	1.25–1.50 cm	1.00–1.25 cm	0.45–0.90 cm	0.0–0.45 cm	
<i>Melasis buprestoides</i> (L.)	1	-	-	-	-	-	-	
Helodidae								
Helodidae Gen. & spp. Indet.	1	-	1	-	-	-	1	
Dermestidae								
<i>Megatoma undata</i> (L.)	-	-	-	-	1	-	-	
Cryptophagidae								
<i>Telomatophilus</i> spp.	-	-	-	-	-	1	-	
Phalacridae								
<i>Phalacrus</i> spp.	-	1	1	-	-	-	1	
Scarabaeidae								
<i>Aphodius</i> spp.	1	-	-	-	-	-	-	
Chrysomelidae								
<i>Donacia semicuprea</i> Panz.	-	-	-	-	2	1	1	On <i>Glyceria</i> spp. (sweet grasses)
<i>Donacia cinerea</i> Hbst.	-	-	-	-	2	1		Usually on <i>Typhea</i> spp. (Bulrush)
<i>Donacia</i> spp.	-	-	1	-	-	-	-	
<i>Plateumaris braccata</i> (Scop.)	-	-	1	1	2	1	2	<i>Phragmites australis</i> (Cav.) Trin. ex Steud. (Common reed)
<i>Crepidodera</i> sp.	-	-	-	-	1	-	-	
Curculionidae								
<i>Rhynchites</i> spp.	-	1	-	-	-	-	-	Mainly on ROSACEAE shrubs
<i>Bagous</i> spp.	-	1	-	-	-	-	-	
<i>Tanysphyrus lemnae</i> (Payk.)	1	-	1	-	-	-	1	<i>Lemna</i> spp. (Duckweed)
<i>Curcio</i> spp.	1	-	-	1	-	-	-	
<i>Limnobaris pilistriata</i> (Steph.)	-	-	-	1	-	-	-	JUNCACEAE -CYPERACEAE (rushes)

Appendix D — Results of the Beetle Assessments

Notes on plant remains and other components of the samples from the Humber REC cores. Within each core the sample are presented in depth order from highest to lowest, with the addition of sample numbers given by PRS during processing.

Core/Depth (cm)	Sample	Wt (kg)	Vol. (l.)	Notes
VC29b				
72–98	3	1.6	1.5	<p>The very small flot consisted primarily of remains of insects and mites; there were a few chenopod seeds, mainly large <i>Atriplex</i>, presumably the large-seeded forms of, for example, <i>A. littoralis</i>.</p> <p>The small residue of barely 100 cm³ comprised plant detritus, including some small ‘stiff’ rhizome fragments (with rather thick cortices), and a few cm³ of marine shell fragments. Apart from some further <i>Atriplex</i> seeds, the few identifiable remains were consistent with freshwater deposition, though the presence of moderate numbers of oak (<i>Quercus</i>) bud-scales points to a terrestrial component.</p>
98–124	12	1.5	1.5	<p>This sample produced a very small flot comprising a very little fine plant detritus and some insects.</p> <p>There was a small residue of barely 100 cm³ of fine plant detritus but including one quite large lump (to 55 mm in maximum dimension) of wood whose shape (that of an orange segment) is presumably a function of cutting through a branch by the coring operation. It has been tentatively identified through thin-sectioning as Pomoideae, a group which includes hawthorn, rowan, wild apple and pear. For the rest there were small wood fragments, oak bud-scales and some more of the ‘stiff’ rhizome fragments seen in the layer above, together with a few scraps of moss, mainly woodland taxa (<i>Homalothecium sericeum</i> (Hedw.) Br. Eur./H. <i>lutescens</i> (Hedw.) Robins., <i>Hypnum</i> cf. <i>cupressiforme</i> Hedw., <i>Leucodon sciuroides</i> (Hedw.) Schwaegr. and <i>Neckera complanata</i> Hedw., but also isolated leaves of Sphagnum), and a few very small grass caryopses.</p>
124–150	4	1.9	1.75	<p>The smallish flot contained quite a lot of tiny (<1 mm) irregular-shaped pellets of undisaggregated silty sediment and oak bud-scales, together with some beetles; there was one very flattened and eroded fruitstone reminiscent of a small wild plum/bullace (<i>Prunus domestica</i> ssp. <i>insititia</i> (L.) C. K. Schneider).</p> <p>The moderately large residue of about 300 cm³ (of which barely 25 cm³ was sand and gravel) comprised woody debris, mainly from oak and including short (to 15 mm) lengths of twig with buds, many detached bud-scales, flattened acorn cup fragments (and some almost complete cupules), and what seemed to be immature acorns; there were also a few fragments of hazel (<i>Corylus avellana</i> L.) nutshell and at least one fruitstone of dogwood, <i>Cornus sanguinea</i> L. The few scraps of moss were, again, likely to be woodland taxa. Curiously there were also many sclerotia of <i>Cenococcum</i>, presumably (with the remains from the oak trees) representing inwash of soils. The other fruits and seeds were either consistent with wet woodland (e.g. woody nightshade, <i>Solanum dulcamara</i> L.) or wetland taxa growing nearer to the point of deposition.</p>

Core/Depth (cm)	Sample	Wt (kg)	Vol. (l.)	Notes
150–176	13	1.4	1.5	The very small washover consisted of a few cm ³ of tiny very decayed rootlets, together with a few <i>Cenococcum sclerotia</i> . The very small residue of about 50 cm ³ was sand and gravel (to 25 mm).
190–202	2	0.8	0.75	There was a very small washover of a couple of cm ³ of sand with a few fragments of very decayed herbaceous detritus, perhaps including roots/ rootlets; there were also some tiny fragments of very decayed coal (from drift). The small dry residue was of sand and gravel (to 10 mm), and amounted to about 60 cm ³ .
VC48				
28–60	8	2.1	2	The small flot was mainly herbaceous detritus. The small residue of about 140 cm ³ consisted of fine plant detritus, the coarser fragments noted as ‘stiff’ rhizome fragments; there were some tiny scraps of moss, including <i>Sphagnum</i> leaves, and a small assemblage of fruits and seeds all from taxa likely to have grown in freshwater fen or marsh: gypsywort (<i>Lycopus europaeus</i> L.), celery-leaved crowfoot (<i>Ranunculus sceleratus</i> L.), water crowfoot (<i>Ranunculus</i> Subgenus <i>Batrachium</i>), reedmace (<i>Typha</i> sp(p).) and stinging nettle (<i>Urtica dioica</i> L.). There were also, somewhat contradictorily, some marine mollusc shell fragments.
64–94	9	1.95	2	The small flot contained few identifiable plant remains, whilst the small residue of about 200 cm ³ mainly consisted of fine plant detritus, much of it rhizome fragments of both flimsy and more rigid character. Apart from traces of Characeae (stonewort) oogonia, the only identified remains were fruits of the horned pondweed <i>Zannichellia</i> .
98–128	5	2	2	This subsample generated a rather large flot containing herbaceous detritus and beetles. A large residue of about 750 cm ³ comprised plant detritus with no mineral component. It had a very ‘flaky’ character and consisted mainly of compressed ‘stiff’ rhizome fragments. There were rather few propagules, but all pointed to a freshwater wetland environment, though sea clubrush, <i>Scirpus maritimus</i> L., if correctly identified, hints at some marine influence.
132–160	11	2.1	1.75	The small flot was mainly rootlets and herbaceous detritus with a single sedge (<i>Carex</i>) nutlet. The residue was rather large (about 440 cm ³), comprising a modest-sized washover of about 140 cm ³ of flaky plant detritus (mainly unidentified herbaceous detritus and some rhizome fragments) and a rather large residue of about 300 cm ³ of sand and gravel, including flint, to 10 mm. The washover contained a little wood charcoal (to 5 mm) and some (apparently) charred <i>Cenococcum</i> and ?woody roots. The finest fraction was perhaps mainly small root/rootlet fragments.

Core/Depth (cm)	Sample	Wt (kg)	Vol. (l.)	Notes
VC50				
22–62	7	3	2.75	There was a small flot of herbaceous detritus and beetles but also containing fruits of the beaked tasselweed, <i>Ruppia maritima</i> L., a plant of brackish water. The other fruits and seeds in the flot, and in the moderate-sized residue of about 340 cm ³ (of which about 80 cm ³ was sand and marine mollusc shell, the rest fine plant detritus) were essentially freshwater aquatic or marsh/fen plants, primarily <i>Potamogeton</i> but including three fruits of the floating water-plantain, <i>Luronium natans</i> (L.) Raf. The latter was not recorded from British Holocene (or indeed any other) deposits at the time of Godwin's (1975) compilation, though there seems to be no particular reason why it should not have been. 'It occurs in a range of freshwater situations but thrives best in open areas with a moderate degree of disturbance, where the growth of emergent vegetation is held in check.' (UKBAP n.d.).
66–120	10	4	2.5	There was a moderately large flot, mainly 'flaky' herbaceous detritus (sometimes with pyrites precipitation) and a few brackish-water/freshwater snails; there were rather few beetles and apparently no propagules. The moderately large residue of about 520 cm ³ included a few cm3 of marine mollusc shell and the <1 mm fraction was large. There were some large endocarps of <i>Potamogeton</i> , often silt-coated, and perhaps all one species, but this was the only identifiable material, indicating extremely low diversity!
124–178	1	3.5	2.5	The small flot comprised flaky herbaceous detritus and beetles with quite a lot of brackish-water/freshwater snails. The presence of <i>Ruppia</i> fruits, some very well preserved and bearing a good part of their pedicels, also points to brackish conditions. The small residue of about 260 cm ³ was of fine organic debris amongst which were about 30 cm ³ of marine shell. The herbaceous detritus was rather fibrous and there were some dark glossy leafless moss stems. More well-preserved <i>Ruppia</i> fruits were present here but the pondweed fruits were often silted and were perhaps further-travelled than the tasselweed. A few more <i>Luronium</i> fruits were present, a further indicator of fresh- rather than brackish water, and it may be no coincidence that these were rather eroded (and, like the pondweeds, perhaps transported from elsewhere).

Core/Depth (cm)	Sample	Wt (kg)	Vol. (l.)	Notes
178–240	6	3.4	2.75	This subsample produced a rather large flot, essentially of herbaceous detritus and some rather well preserved beetles, together with a few pondweed pyrenes, a tiny oak bud-scale and a fruitstone of dogwood. There were also quite a lot of tiny ?freshwater molluscs. <i>Ruppia</i> was again present. The small to moderate-sized residue of about 500 cm ³ included about 250 cm ³ of fragments of marine mollusc shell, the rest being plant detritus, mainly coarse stiff rhizome of the kind seen in several other samples, together with a further dogwood fruitstone and modest numbers of oak bud-scales and pondweed pyrenes.
VC51a				
10–47	14	1.8	1.75	There was a small flot, mainly herbaceous detritus and beetles. The moderate-sized res of about 200 cm ³ was of organics, with sand and shell fragments making up about 80 cm3. The stiff flattened rhizome fragments were again present. The only identified propagules were those of reedmace (<i>Typha</i>).
47–95	15	2.4	2.25	A small flot here comprised rather flaky herbaceous detritus, plus well preserved beetles, and frequent reedmace propagules, with a small range of other freshwater marsh/fen edge taxa. There were two fruitstones of wild plum/bullace, one of them very distorted. The moderately large residue of about 350 cm ³ consisted of woody detritus and undisaggregated silty sediment, amongst which was about 75 cm ³ sand and flint (to 20 mm). The woody fragments seemed mainly to be bark (and maybe some bast fibre from beneath it); there was also some wood charcoal (to 25 mm) and rhizome fragments, again very stiff and almost 'woody', flattened, sometimes slightly pyritized. A further wild plum/bullace fruitstone was present here together with a few pondweed pyrenes (more than one species), a few fragments of moss (<i>Neckera complanata</i>) and a small range of other taxa all likely to have come from freshwater marsh or fen, with reedmace the most abundant.

Lists of plant taxa and other components of the core samples in alphabetic order by cored and depth ('Context' 7298 translates as depth 72–98 cm and so on).

Abbreviations: b/b–buds and/or bud-scales; ch–charred;

imm–immature; fgts–fragments; fr–fruits; lf–leaf; lfless–leafless; lvs–leaves; rh–rhizome; tw–twig.

Core	Context	Sample	Taxon	Note
VC29b	7298	3	Atriplex sp(p).	
VC29b	7298	3	beetles	
VC29b	7298	3	Cenococcum (sclerotia)	
VC29b	7298	3	coal	maximum dimension 2 mm
VC29b	7298	3	Cristatella (statoblasts)	
VC29b	7298	3	dicot lf fgts	
VC29b	7298	3	fine plant detritus	
VC29b	7298	3	fly puparia	
VC29b	7298	3	foraminifera	
VC29b	7298	3	Gramineae	
VC29b	7298	3	herbaceous detritus	
VC29b	7298	3	marine mollusc shell fgts	
VC29b	7298	3	mites	
VC29b	7298	3	Quercus sp(p). (b/bs)	
VC29b	7298	3	Ranunculus Subgenus Batrachium	
VC29b	7298	3	rhizome fgts	maximum dimension 10 mm
VC29b	7298	3	sand	
VC29b	7298	3	Scirpus cf. lacustris sl	
VC29b	7298	3	Typha sp(p).	
VC29b	7298	3	wood fgts	maximum dimension 5 mm
VC29b	98124	12	beetles	
VC29b	98124	12	cf. Pomoideae (wood)	maximum dimension 55 mm
VC29b	98124	12	dicot lf fgts	
VC29b	98124	12	Dicranum sp(p).	detached leaf/leaves only
VC29b	98124	12	fine plant detritus	
VC29b	98124	12	fly puparia	
VC29b	98124	12	Gramineae	
VC29b	98124	12	gravel	maximum dimension 5 mm
VC29b	98124	12	herbaceous detritus	
VC29b	98124	12	Homalothecium sericeum/lutescens	
VC29b	98124	12	Hypnum cf. cupressiforme	
VC29b	98124	12	Leucodon sciuroides	
VC29b	98124	12	moss (lfless stems)	
VC29b	98124	12	Neckera complanata	
VC29b	98124	12	Polygonum cf. lapathifolium	
VC29b	98124	12	Quercus sp(p). (b/bs)	
VC29b	98124	12	rhizome fgts	maximum dimension 5 mm
VC29b	98124	12	Scirpus lacustris sl	
VC29b	98124	12	Sphagnum sp(p). (lvs)	

Core	Context	Sample	Taxon	Note
VC29b	98124	12	wood fgts	maximum dimension 55 mm
VC29b	124150	4	Antitrichia curtipendula	
VC29b	124150	4	Atriplex sp(p).	
VC29b	124150	4	bark fgts	maximum dimension 10 mm
VC29b	124150	4	beetles	
VC29b	124150	4	Cenococcum (sclerotia)	
VC29b	124150	4	Cornus sanguinea	
VC29b	124150	4	Corylus avellana	
VC29b	124150	4	dicot lf fgts	
VC29b	124150	4	fine plant detritus	
VC29b	124150	4	flint	maximum dimension 15 mm
VC29b	124150	4	fly puparia	
VC29b	124150	4	gravel	maximum dimension 15 mm
VC29b	124150	4	herbaceous detritus	
VC29b	124150	4	Homalothecium sericeum/lutescens	
VC29b	124150	4	Hypnum cf. cupressiforme	
VC29b	124150	4	leaf ab pads	
VC29b	124150	4	Neckera complanata	
VC29b	124150	4	Quercus sp(p). (b/bs)	
VC29b	124150	4	Quercus sp(p). (cup fgts)	
VC29b	124150	4	Quercus sp(p). (imm fr)	
VC29b	124150	4	Quercus sp(p). (tw fgts)	maximum dimension 15 mm
VC29b	124150	4	Ranunculus sceleratus	
VC29b	124150	4	sand	
VC29b	124150	4	Scirpus cf. maritimus	
VC29b	124150	4	small mammal tooth	
VC29b	124150	4	Solanum dulcamara	
VC29b	124150	4	twig fgts	maximum dimension 15 mm
VC29b	124150	4	unwashed clay sediment	maximum dimension 5 mm
VC29b	124150	4	woody root fgts	maximum dimension 5 mm
VC29b	150176	13	Cenococcum (sclerotia)	
VC29b	150176	13	gravel	maximum dimension 25 mm
VC29b	150176	13	root bark/epidermis fgts	maximum dimension 5 mm
VC29b	150176	13	root/rootlet fgts	
VC29b	150176	13	sand	
VC29b	150176	13	wood fgts	very decayed, maximum dimension 5 mm
VC29b	150176	13	woody root fgts	maximum dimension 5 mm
VC29b	190202	2	coal	maximum dimension 2 mm

Core	Context	Sample	Taxon	Note
VC29b	190202	2	fine plant detritus	
VC29b	190202	2	gravel	maximum dimension 10 mm
VC29b	190202	2	sand	
VC48	2860	8	beetles	
VC48	2860	8	cf. Amblystegium sp(p).	
VC48	2860	8	Cristatella (statoblasts)	
VC48	2860	8	fly puparia	
VC48	2860	8	Gramineae	
VC48	2860	8	herbaceous detritus	
VC48	2860	8	Lophopus crystallinus	
VC48	2860	8	Lycopus europaeus	
VC48	2860	8	marine mollusc shell fgts	
VC48	2860	8	moss (lfless stems)	
VC48	2860	8	ostracods	
VC48	2860	8	Ranunculus sceleratus	
VC48	2860	8	Ranunculus Subgenus Batrachium	
VC48	2860	8	rhizome fgts	maximum dimension 15 mm
VC48	2860	8	Sphagnum sp(p). (lvs)	
VC48	2860	8	Typha sp(p).	
VC48	2860	8	Urtica dioica	very decayed
VC48	6494	9	beetles	
VC48	6494	9	Characeae	
VC48	6494	9	fine plant detritus	
VC48	6494	9	fly puparia	
VC48	6494	9	herbaceous detritus	
VC48	6494	9	moss (lfless stems)	
VC48	6494	9	ostracods	
VC48	6494	9	Phragmites australis (rh fgts)	maximum dimension 40 mm
VC48	6494	9	rhizome fgts	
VC48	6494	9	Zannichellia sp(p).	
VC48	98128	5	beetles	
VC48	98128	5	Berula erecta	
VC48	98128	5	Carex sp(p).	
VC48	98128	5	Characeae	
VC48	98128	5	Elatine hydropiper	
VC48	98128	5	fine plant detritus	
VC48	98128	5	fly puparia	
VC48	98128	5	Gramineae	very small type(s)
VC48	98128	5	herbaceous detritus	
VC48	98128	5	mites	
VC48	98128	5	Phragmites australis (rh fgts)	maximum dimension 10 mm
VC48	98128	5	Ranunculus Subgenus Batrachium	

Core	Context	Sample	Taxon	Note
VC48	98128	5	rhizome fgts	maximum dimension 15 mm
VC48	98128	5	Scirpus maritimus	
VC48	98128	5	Solanum dulcamara	
VC48	98128	5	Typha sp(p).	
VC48	98128	5	unwashed peaty sediment	maximum dimension 10 mm
VC48	98128	5	Urtica dioica	
VC48	98128	5	Zannichellia sp(p).	
VC48	132160	11	?root/rhizome fgts (ch)	maximum dimension 3 mm
VC48	132160	11	Carex sp(p).	
VC48	132160	11	Cenococcum (ch sclerotia)	
VC48	132160	11	charcoal	maximum dimension 5 mm
VC48	132160	11	Cornus sanguinea	
VC48	132160	11	Corylus avellana	
VC48	132160	11	fine plant detritus	
VC48	132160	11	gravel	maximum dimension 35 mm
VC48	132160	11	herbaceous detritus	
VC48	132160	11	rhizome fgts	maximum dimension 25 mm
VC48	132160	11	root/rootlet fgts	
VC48	132160	11	sand	
VC48	132160	11	unwashed peaty sediment	maximum dimension 10 mm
VC48	132160	11	woody root fgts	maximum dimension 10 mm
VC50	2262	7	beetles	
VC50	2262	7	Carex sp(p).	
VC50	2262	7	fine plant detritus	
VC50	2262	7	fly puparia	
VC50	2262	7	freshwater snails	
VC50	2262	7	herbaceous detritus	
VC50	2262	7	Luronium natans	
VC50	2262	7	Lycopus europaeus	
VC50	2262	7	marine mollusc shell fgts	
VC50	2262	7	mites	
VC50	2262	7	moss	
VC50	2262	7	moss (lfless stems)	maximum dimension 20 mm
VC50	2262	7	Potamogeton sp(p).	
VC50	2262	7	Quercus sp(p). (b/bs)	
VC50	2262	7	Ruppia maritima	
VC50	2262	7	sand	
VC50	2262	7	Scorpidium scorpioides	
VC50	2262	7	Sphagnum sp(p). (lvs)	sp., not papillosum or imbricatum
VC50	2262	7	Typha sp(p).	
VC50	66120	10	beetles	
VC50	66120	10	fine plant detritus	

Core	Context	Sample	Taxon	Note
VC50	66120	10	freshwater snails	
VC50	66120	10	gravel	maximum dimension 10 mm
VC50	66120	10	herbaceous detritus	
VC50	66120	10	marine mollusc shell fgts	
VC50	66120	10	Potamogeton sp(p).	
VC50	66120	10	unwashed clay sediment	maximum dimension 5 mm
VC50	124178	1	Atriplex sp(p).	
VC50	124178	1	beetles	
VC50	124178	1	colonial hydroid	maximum dimension 10 mm
VC50	124178	1	Eupatorium cannabinum	
VC50	124178	1	fine plant detritus	
VC50	124178	1	freshwater snails	
VC50	124178	1	herbaceous detritus	
VC50	124178	1	Luronium natans	
VC50	124178	1	marine mollusc shell fgts	
VC50	124178	1	mites	
VC50	124178	1	moss (lfless stems)	maximum dimension 10 mm
VC50	124178	1	Potamogeton sp(p).	
VC50	124178	1	Quercus sp(p). (b/bs)	
VC50	124178	1	Rumex sp(p). (per/segs)	mostly fragments
VC50	124178	1	Ruppia maritima	
VC50	124178	1	unwashed clay sediment	maximum dimension 5 mm
VC50	124178	1	Zannichellia sp(p).	
VC50	178240	6	beetles	
VC50	178240	6	caddis larva cases	
VC50	178240	6	Cenococcum (sclerotia)	
VC50	178240	6	Characeae	
VC50	178240	6	Cornus sanguinea	
VC50	178240	6	fine plant detritus	
VC50	178240	6	freshwater snails	
VC50	178240	6	herbaceous detritus	
VC50	178240	6	marine mollusc shell fgts	
VC50	178240	6	Potamogeton sp(p).	
VC50	178240	6	Quercus sp(p). (b/bs)	
VC50	178240	6	Ranunculus Subgenus Batrachium	
VC50	178240	6	rhizome fgts	maximum dimension 25 mm
VC50	178240	6	Ruppia maritima	
VC50	178240	6	Salix (wood)	maximum dimension 55 mm
VC50	178240	6	Scirpus cf. lacustris sl	
VC50	178240	6	Scirpus cf. maritimus	
VC50	178240	6	unwashed clay sediment	maximum dimension 5 mm
VC50	178240	6	wood fgts	maximum dimension 55 mm
VC51a	1047	14	barnacle shell fgts	

Core	Context	Sample	Taxon	Note
VC51a	1047	14	beetles	
VC51a	1047	14	fine plant detritus	
VC51a	1047	14	herbaceous detritus	
VC51a	1047	14	marine mollusc shell fgts	maximum dimension 20 mm
VC51a	1047	14	mites	
VC51a	1047	14	Phragmites australis (rh fgts)	maximum dimension 15 mm
VC51a	1047	14	rhizome fgts	maximum dimension 25 mm
VC51a	1047	14	sand	
VC51a	1047	14	stones	maximum dimension 20 mm
VC51a	1047	14	Typha sp(p).	
VC51a	4795	15	?bast fgts	
VC51a	4795	15	bark fgts	maximum dimension 65 mm
VC51a	4795	15	barnacle shell fgts	
VC51a	4795	15	beetles	
VC51a	4795	15	Carex sp(p).	
VC51a	4795	15	Cenococcum (sclerotia)	
VC51a	4795	15	charcoal	maximum dimension 25 mm
VC51a	4795	15	Elatine hydropiper	
VC51a	4795	15	Eupatorium cannabinum	
VC51a	4795	15	fine plant detritus	
VC51a	4795	15	flint	maximum dimension 20 mm
VC51a	4795	15	herbaceous detritus	
VC51a	4795	15	Lycopus europaeus	
VC51a	4795	15	Mentha sp(p).	
VC51a	4795	15	mites	
VC51a	4795	15	Neckera complanata	
VC51a	4795	15	Phragmites australis (rh fgts)	maximum dimension 15 mm
VC51a	4795	15	Potamogeton sp(p).	
VC51a	4795	15	Prunus domestica ssp. insititia	
VC51a	4795	15	Ranunculus sceleratus	
VC51a	4795	15	Ranunculus Subgenus Batrachium	
VC51a	4795	15	rhizome fgts	maximum dimension 10 mm
VC51a	4795	15	Rumex sp(p). (per/segs)	
VC51a	4795	15	sand	
VC51a	4795	15	Scirpus cf. lacustris sl	
VC51a	4795	15	stones	maximum dimension 30 mm
VC51a	4795	15	twig fgts	maximum dimension 10 mm
VC51a	4795	15	Typha sp(p).	
VC51a	4795	15	unwashed clay sediment	maximum dimension 10 mm

Appendix E — Habitat Suitability Modelling

Table E.1 summarises the data layers which have been used the EUNIS and RECHUMB models. Details of their GIS processing is provided in this Appendix together with additional information on how model layers were categorised. The location of figures presenting each of the layers is shown in the last column of the table.

Layer Type	Parameter	Model Applied to	Figure No.
Geology	Folk seabed sediment	EUNIS	BGS to insert figure number
	Gravel percentage	RECHUMB	4.2.11 & C.1.2.1
	Mud percentage	RECHUMB	4.2.13 & C.1.2.2
	Bedform type	RECHUMB	4.2.5
	Bedrock	EUNIS & RECHUMB	4.2.6
	Botney Cut	RECHUMB	4.2.17
Bed stress	Tidal currents	EUNIS	7.1.5
	Maximum wave and tidal bed shear stress	RECHUMB	C.1.2.3 & C.1.2.4
Water Column	Near bed salinity	RECHUMB	C.1.2.5 & C.1.2.6
	Near bed temperature	RECHUMB	C.1.2.7 & C.1.2.8
	Winter water column types	RECHUMB	C.1.2.9
Bathymetry	Bathymetry/depth	EUNIS & RECHUMB	BGS to insert figure number
	Slope	RECHUMB	C.1.2.10 & C.1.2.11
Biological zones	Photic maximum	EUNIS & RECHUMB	7.1.1
	Wavebase	EUNIS & RECHUMB	7.1.2

Table E.1 Summary of data layers used to model biotopes across the Humber REC study area

GEOLOGY

Folk sea bed sediment

Data Supplied

BGS supplied the level 3 EUNIS sediment and folk sediment layers in shapefile format.

Processing

The level three EUNIS sediment layer was subdivided into level 4 using a Union in ArcTools. The sediment trigon rules shown in Figure 7.1.3 were then applied using the Field Calculator in the Attribute Table to choose relevant categories, after which the layer was Dissolved (ArcTools) to amalgamate classes into one entry.

Gravel percentage, Mud percentage

Data Supplied

BGS supplied full regional coverage of percentage gravel, mud (and sand though out ruled in model) percentage maps in raster format.

Processing

These were reclassified as detailed below (see Model Classification).

Bedrock, Bolders Bank, Botney Cut, Bedform type

Data Supplied

BGS supplied GIS full regional coverage vector layers of bedform types, boulder presence, bedrock outcrop and presence in shapefile format. See Figures 4.2.5, 4.2.6 and 4.2.17 and GIS Layers: ‘Bedforms100k_new’, ‘Botney Cut New’, and ‘Revised bedrock outcrop’.

Processing

No processing was necessary prior to use in the models.

BED STRESS

Tidal currents

Data Supplied

Tidal velocity raster data using the maximum amplitude of the depth averaged mean spring tidal current (ms⁻¹) was provided by BGS via POL (M J Howarth) © NERC.

Processing

Data were classified using the Raster Calculator (Spatial Analyst) into the EUNIS categories of low, moderate, strong (0–0.5m/s, 0.5–1.5m/s, 1.5–3m/s) and then converted to a shapefile polygon. This was smoothed owing to the apparent model grid structure remaining in the shapes, using the ET GeoWizard V9.9 B-spline method.

Maximum wave and tidal bed shear stress

Data Supplied

These were supplied from UKSeaMap2010 in raster format as provided via MALSF from ABPmer, in agreement with JNCC and Defra prior to its official public release.

Processing

Data were classified as detailed below (see Model Classification).

WATER COLUMN

Near bed salinity and near bed temperature

Data Supplied

These were supplied via MyOCean (sourced from Proudman Oceanographic Laboratory) in ascii format. For more information see <http://www.myocean.eu.org>

Processing

Data was imported to ArcGIS using the Ascii to Raster AcrTool and exported as raster files. Data were then classified as detailed below (see Model Classification).

Winter water column types

Data Supplied

Data on winter water column types came from UKSeaMap2010 in shapefile format. The categories within the Humber REC area were 1. Well-mixed region of freshwater influence (ROFI) and 2. Well-mixed shelf water.

Processing

The shapefile was smoothed owing to the apparent model grid structure remaining in the shapes, using the ET GeoWizard V9.9 B-spline method.

BATHYMETRY

Bathymetry/depth, slope and rugosity

Data Supplied

BGS supplied high resolution raster bathymetry data (<200 m resolution as plotted) that incorporated source data from SeaZone and further processed at BGS. BGS to insert copyright for dataset here.

The British Oceanographic Data Centre supplied coarse resolution GEBCO raster bathymetry data © NERC

Processing

Several stations were outside the area or located in gaps in the data. Therefore the following steps were taken to ensure they could be allocated depths:

- Pixels with no data next to pixels with data were assigned an average of the 4 x 4 surrounding cells using Spatial Analyst
- This was carried repeated on each output dataset so it was carried out a total of three times
- Any remaining gaps were infilled with GEBCO bathymetry

From the processed bathymetry dataset, slope (in degrees and percent) was calculated using ArcGIS Spatial Analyst. Rugosity was also calculated using the Benthic Terrain Modeler add on to ArcGIS. Rugosity is a ratio of surface area to planar area.

BIOLOGICAL ZONES

Photic maximum

Data Supplied

UKSeaMap 2006 data (Connor *et al* 2006) was supplied by Defra in the format of raster data values of the mean annual depth to which 1% of surface light penetrates the water column. This dataset was sourced during UKSeaMap 2006 from SeaSiFS via POL. The quality of the data has been stated by the suppliers as poor and with errors. As such, we were informed that UKSeaMap 2010 data would reduce these errors significantly but these are not available until after the Humber REC habitat modeling is to be completed.

Processing

The data were overlaid with the BGS/SeaZone bathymetry data to extract areas where the 1% irradiance reaches the seabed. The output produced was a raster map showing photic and aphotic areas within the study area. Less than 1% of the total study area was assigned the photic class, which was all <30 km of the Wash. As the bathymetry accuracy reduces towards this area in particular, it was concluded that this could not be relied on when considering the accuracy of the light penetration dataset is in itself with significant error. Therefore, all areas have been assigned the aphotic category in the RECHUMB model.

Wavebase

Data Supplied

UKSeaMap 2006 data (Connor *et al* 2006) was supplied by Defra (sourced from POL) in the format of raster data values of maximum depth to which waves penetrate the water column.

Processing

The data were overlaid with the BGS/SeaZone bathymetry data to extract areas where the wavebase reaches the seabed. The output produced was a raster map showing shallow (less than wave base) and shelf (greater than wave base) areas within the study area. The raster was then converted to shapefile polygon to allow the EUNIS model to be built. This polygon layer was smoothed using the ET GeoWizard V9.9 B-spline method to form a non-gridded structure with what appears to be good results.

MODEL GIS PROCESSES

Model classification

All numerical GIS datasets were transformed to classified layers (values 1 to 6) using the following steps:

- Values multiplied by a factor of 10 (Spatial Analyst Raster Calculator)
- Values converted to integer format (Raster Calculator)
- Values reclassified, i.e. assigned a new value of between 1 and 6 based on values in Table 7.2.2 (Raster Calculator)
- Layer converted from raster to shapefile (Spatial Analyst)
- Layer clipped to project area (ArcTools Clip)
- Layer Dissolved to reduce number of attribute entries (ArcTools Dissolve)
- Layer Smoothed where possible using (ET GeoWizard V9.9 B-spline method, default control parameters)

MODEL CREATION

All contributing layers to the EUNIS and RECHUMB models were processed as follows:

- Layers combined to form unique areas (Union ArcTools)
- Layers dissolved to aggregate areas of similar characteristics (Dissolve ArcTools)

- Calculations used based on rules detailed in Chapter 7 (Field Calculator and VBA code)

The contributing layers for the models are shown in Figures E.1.2.1 to E.1.2.11.

Figure E.1.2.1: Percentage gravel converted to classified scoring for the RECHUMB model (Derived from BGS data)

Figure E.1.2.2: Percentage mud converted to classified scoring for the RECHUMB model (Derived from BGS data)

Figure E.1.2.3: Maximum wave and tidal bed shear stress (Source UKSeaMap2006)

Figure E.1.2.4: Maximum wave and tidal bed shear stress converted to classified scoring for the RECHUMB model (Derived from UKSeaMap2006 data)

Figure E.1.2.5: Near bed salinity (Source MyOcean/Proudman Oceanographic Laboratory)

Figure E.1.2.6: Near bed salinity converted to classified scoring for the RECHUMB model (Derived from MyOcean/POL data)

Figure E.1.2.7: Near bed temperature (Source MyOcean/Proudman Oceanographic Laboratory)

Figure E.1.2.8: Near bed temperature converted to classified scoring for the RECHUMB model (Derived from MyOcean/POL data)

Figure E.1.2.9: Winter water body types (Source UKSeaMap2006)

Figure E.1.2.10: Slope in degrees (Derived from bathymetry data sourced from SeaZone/BGS)

Figure E.1.2.11: Slope in degrees converted to classified scoring for the RECHUMB model (Derived from SeaZone/BGS bathymetry data)

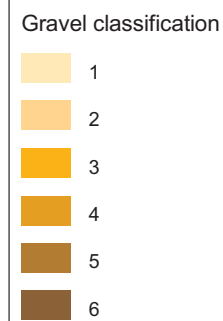
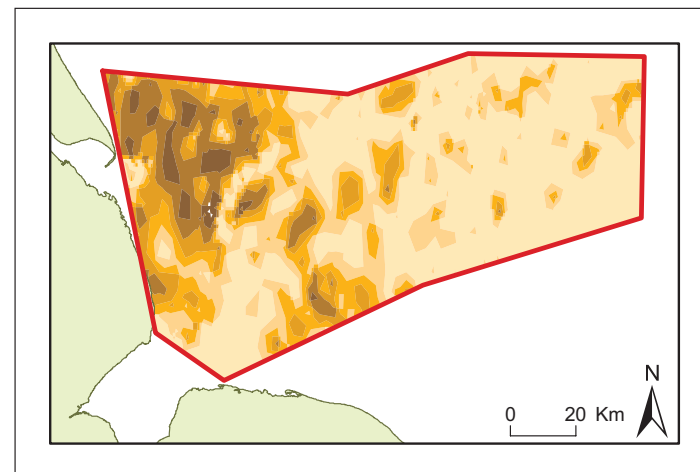


Figure E.1.2.1: Percentage gravel converted to classified scoring for the RECHUMB model (Derived from BGS data).

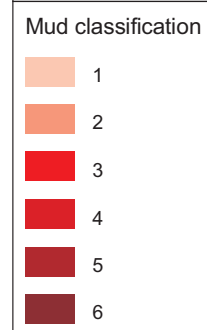
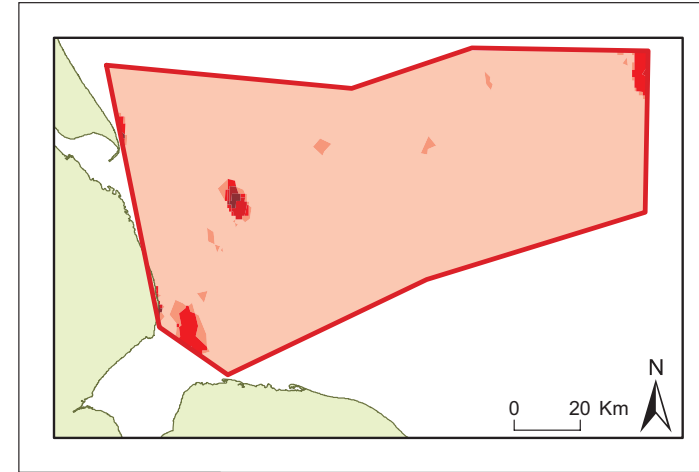


Figure E.1.2.2: Percentage mud converted to classified scoring for the RECHUMB model (Derived from BGS data).

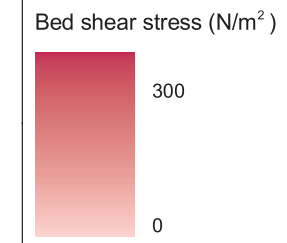
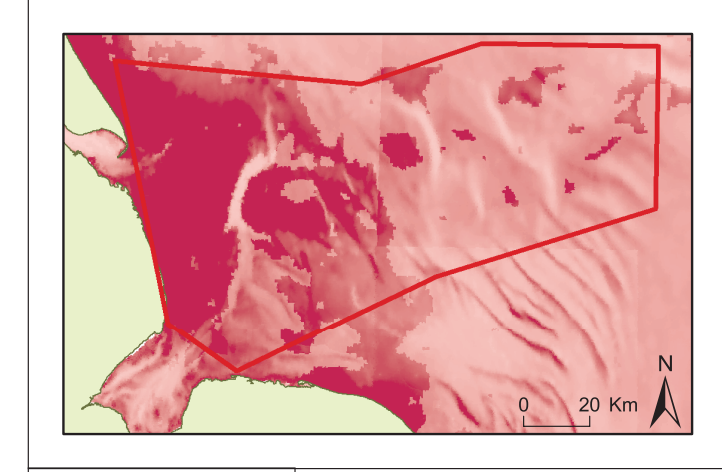


Figure E.1.2.3: Maximum wave and tidal bed shear stress (Source UKSeaMap2006).

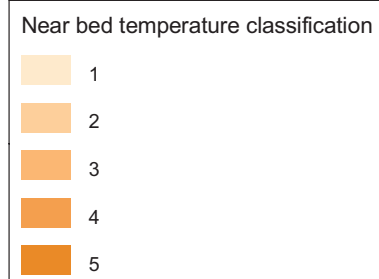
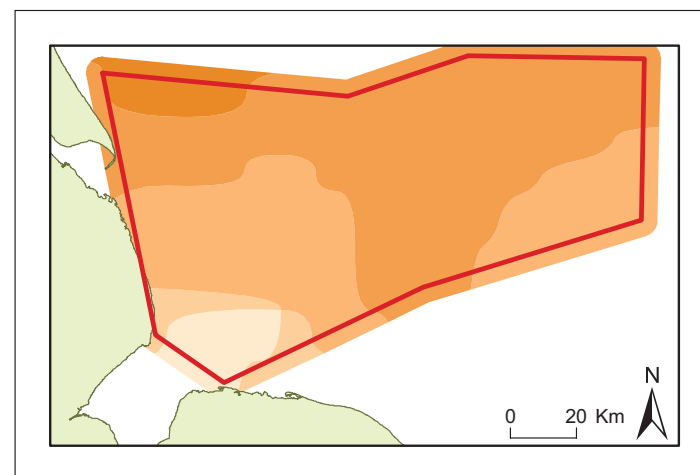


Figure E.1.2.4: Maximum wave and tidal bed shear stress converted to classified scoring for the RECHUMB model (Derived from UKSeaMap2006 data).

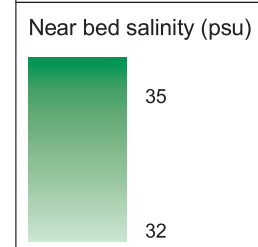
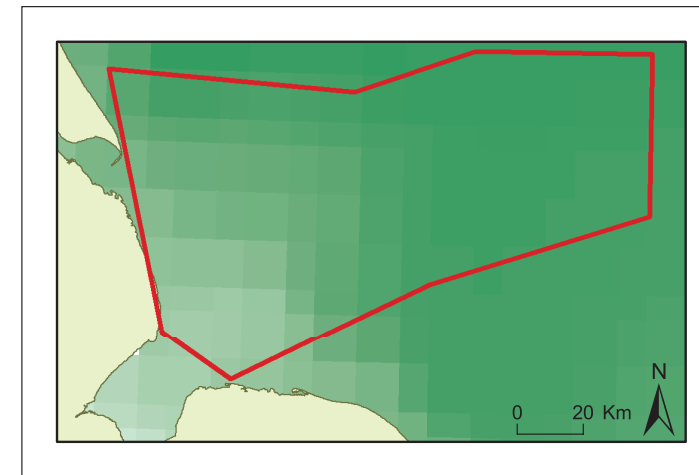


Figure E.1.2.5: Near bed salinity (Source MyOcean/Proudman Oceanographic Laboratory).

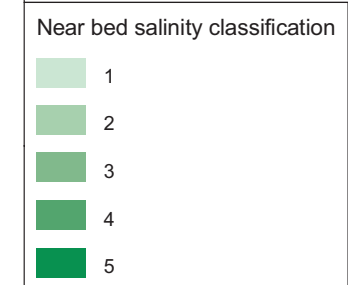
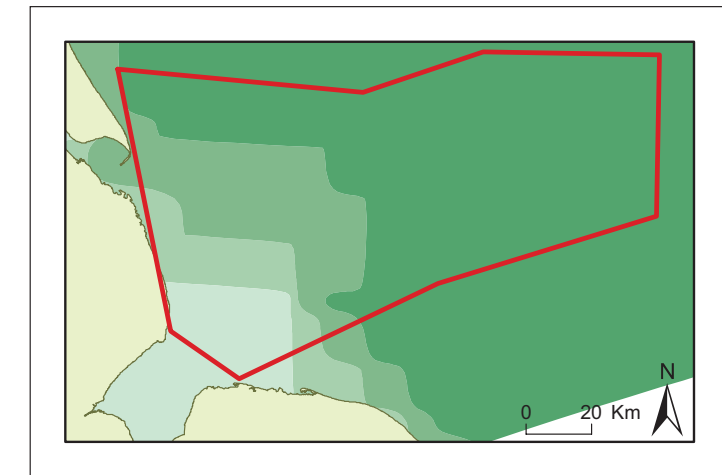


Figure E.1.2.6: Near bed salinity converted to classified scoring for the RECHUMB model (Derived from MyOcean/POL data).

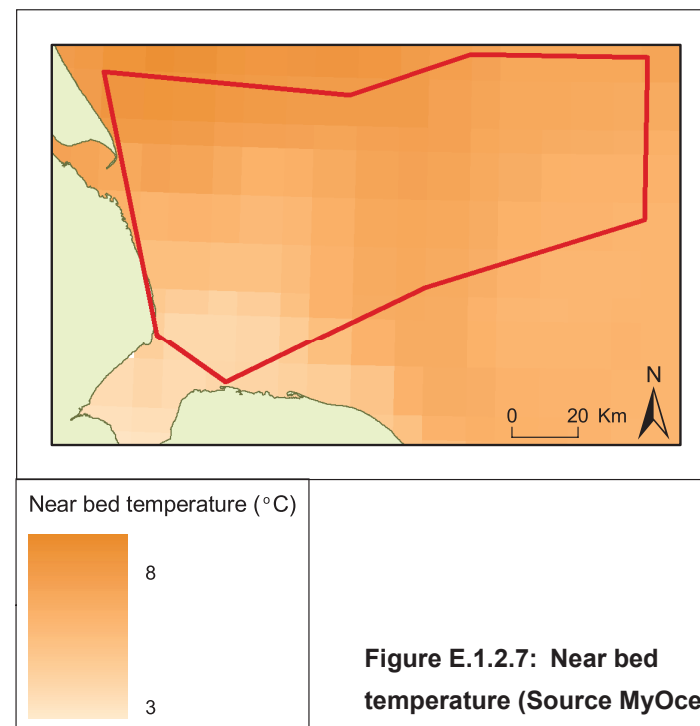


Figure E.1.2.7: Near bed temperature (Source MyOcean/ Proudman Oceanographic Laboratory).

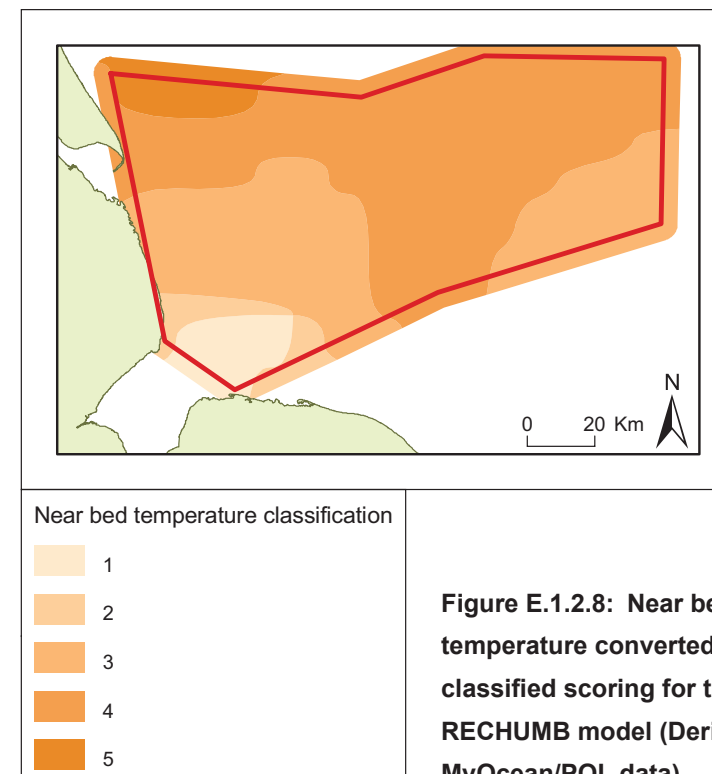


Figure E.1.2.8: Near bed temperature converted to classified scoring for the RECHUMB model (Derived from MyOcean/POL data).

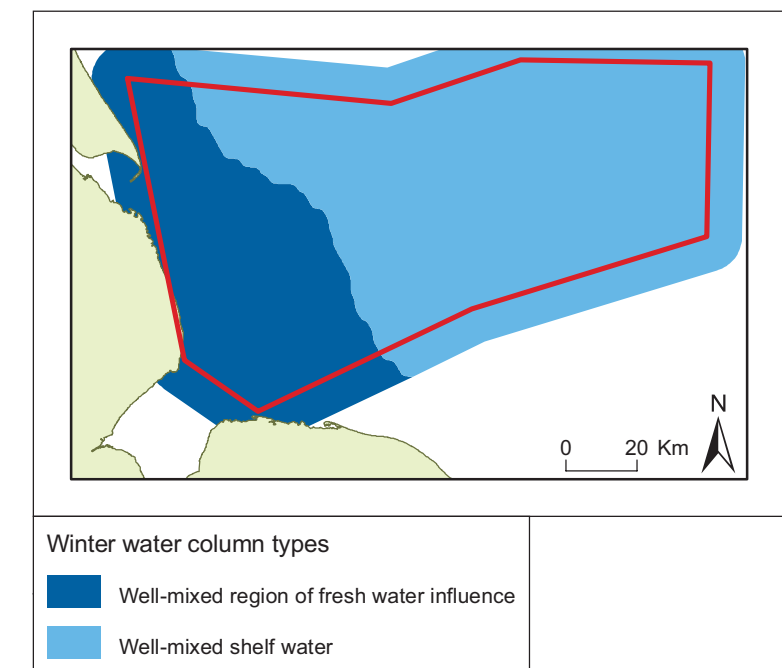


Figure E.1.2.9: Winter water body types (Source UKSeaMap2006).

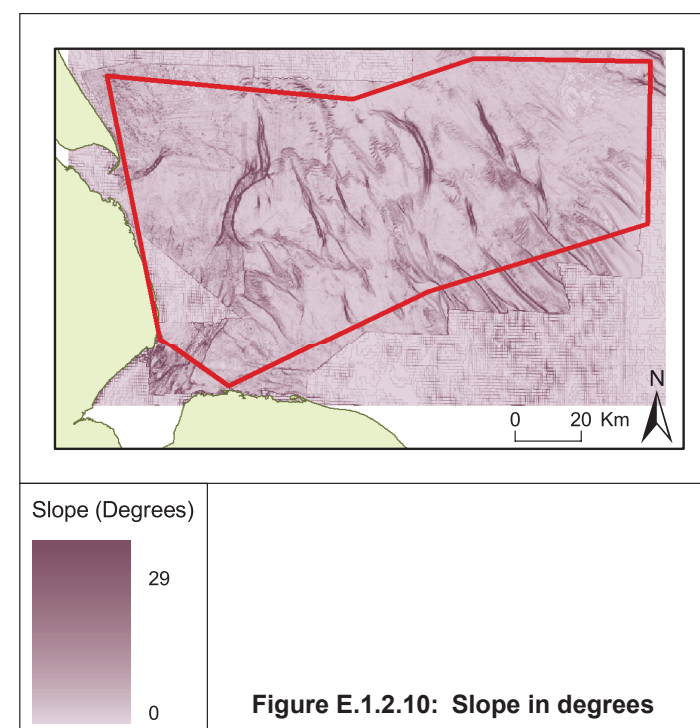


Figure E.1.2.10: Slope in degrees (Derived from bathymetry data sourced from SeaZone/BGS).

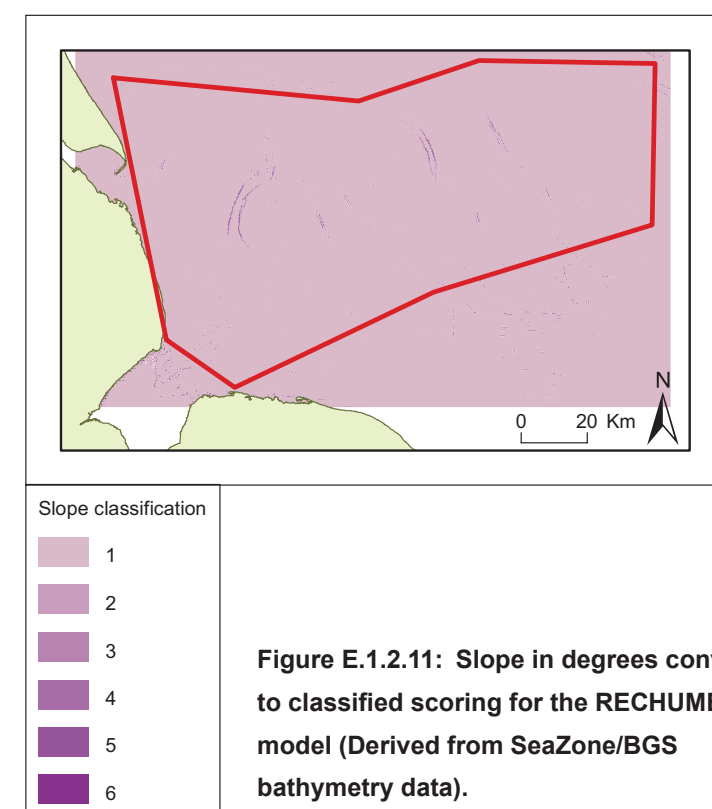
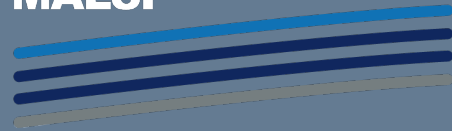


Figure E.1.2.11: Slope in degrees converted to classified scoring for the RECHUMB model (Derived from SeaZone/BGS bathymetry data).

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